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FINAL REPORT

EFFECTS OF CONCENTRATED HYDROGEN PEROXIDE ON MECHANICAL AND CORROSION PROPERTIES OF STRUCTURAL ALUMINUM ALLOYS

BUREAU OF SHIPS [illegible]
DEPARTMENT OF THE NAVY
Contract No. NObs-72258

16 February 1959 KC-1164-M-11

B U F F A L O , N E W Y O R K

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY

BUFFALO, N. Y.

REPORT NO. KC-1164-M-11

FINAL REPORT

EFFECTS OF CONCENTRATED HYDROGEN PEROXIDE ON MECHANICAL AND CORROSION PROPERTIES OF STRUCTURAL ALUMINUM ALLOYS

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BUREAU OF SHIPS
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Index Number NS-013-118

By: Franklin J. Gillig
Principal Metallurgist

Approved By: John L. Beal, Head
Materials Department

SUMMARY

Nine wrought and three cast aluminum alloys were exposed to commercial 90% H_2O_2 as manufactured and 90% H_2O_2 with 3 grams per liter chloride ion and 4 grams per liter nitrate ion added. The majority of the exposures were of 6 months duration. Some of the specimens had to be removed prematurely due to severe corrosion or rapid deterioration of the peroxide. Evaluation tests included mechanical properties, stress corrosion, metallographic examination and chemical analyses of the peroxide in order to determine its deterioration. The presence of chloride ion was found to accelerate corrosion greatly in all of the alloys. Wrought alloys 5254 and 3003 were found to be the most compatible and B-214 was the best cast alloy.

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INTRODUCTION

The objective of this investigation was to determine the effects of concentrated hydrogen peroxide on the mechanical and corrosion properties of selected structural aluminum alloys. Although procedures and materials for storing and handling hydrogen peroxide of this concentration were outlined in NAVAER 06-25-501, "Handbook for Field Handling of Concentrated Hydrogen Peroxide", and other industrial manuals, it was felt that these did not adequately cover the situations likely to be encountered in shipboard service. The anticipated size of the storage tanks desired was much larger than those constructed for ordinary usage and they would have to conform to the configuration of the ship in order to make maximum use of available space. These requirements called for the use of higher strength alloys than the commercially pure grades of aluminum normally used for containers and transportation equipment. The possibility of contamination with small amounts of chloride is always a possibility aboard ship and it was desired to study the effect of chloride contamination on the corrosion rate and determine allowable concentrations.

The program was undertaken with the aid of the Special Projects Branch of the Food Machinery and Chemical Corporation who are currently engaged in research with high concentration peroxide. The preparation of specimens and metallurgical evaluation was done at Cornell Aeronautical Laboratory, Inc. and the peroxide exposures and analyses were performed by the above corporation under subcontract.

Nine wrought alloys and three cast alloys were selected for evaluation based upon previous industrial experience with peroxide storage tanks and recommendations of the aluminum producers. The properties of the alloys were evaluated in the "as-received" condition and also as weldments. Stressed specimens were included to determine the possibility of stress corrosion effects. The specimens were exposed for a maximum of 6 months to 90% commercial hydrogen peroxide with and without added chlorides. After exposure they were examined to determine the type and extent of corrosion. Tensile tests on corroded specimens showed the extent of the deterioration of mechanical properties due to exposure. A record of the peroxide concentration was maintained throughout the tests to determine the stability of the solutions in contact with the various specimens.

TEST PROGRAM

The alloys which were evaluated were as follows:

Wrought		Cast
1100-H14	5254-H34	356
1260-H14	6363-T5	43
3003-H14	6061-T6	B-214
5652-H34	5086-H34	
1060-H14		

The above alloys were tested in the "as-received" condition and also as weldments. The base-metal-welding-rod combinations used were as follows:

1100 with parent metal rod

1060 with parent metal rod

1260 with parent metal rod

3003 with parent metal rod

5086 with 5356

5652 with parent metal rod

5254 with parent metal rod

6363 with 4043 controlled* rod

6061 with 4043 controlled* rod

1260 cladding** with 1260 rod

*The controlled 4043 welding rod was alloyed using 99.99% pure aluminum and the finished rod contained 0.001% Cu and 0.024% Mn as impurities.

**The 1260 cladding was obtained by machining away the 5086 core from a one-inch thick plate as shown in Figure 1.

The original program called for exposure to two solutions: 90% commercial grade hydrogen peroxide and the same solution with 20 ppm (parts per million) added chloride. Tests on the first group of welded

and unwelded sheet alloy specimens exposed to the solution containing the 20 ppm chloride had to be discontinued after a 24-hour exposure because of rapid attack on some of the specimens and decomposition of the solutions. These specimens are shown in Figures 2, 3, and 4.

In order to arrive at a more realistic concentration of the chloride for a six-month exposure test, it was decided to try some immersion tests in 90% H_2O_2 solutions containing various amounts of chloride. Solutions were prepared with 0, 2, 4, 6, 8 and 10 mg of chloride ion per liter (multiplying by 1.39 converts these concentrations to ppm). Specimens of two of the alloys presently in use for peroxide storage, 1100 and 1260, were exposed in these solutions for 7 days. The results of these tests are shown in Figures 5 and 6.

Based upon these results and a conference with the technical sponsor, it was decided to use a test solution of 90% H_2O_2 containing 3 mg per liter chloride ion and 4 mg per liter nitrate ion. The nitrate addition was recommended by the peroxide manufacturer as a stabilizer to reduce decomposition of the peroxide due to minor contamination by the corrosion products.

The wrought alloys were procured as 0.065-inch thick sheet and the casting alloys were cast into plates 1/2 inch thick by 9 inches by 9 inches in an iron tilt mold. All alloys and weldments were exposed in both the unstressed and stressed conditions. The unstressed specimens were used for tensile tests subsequent to exposure to determine whether or not exposure to the corrosive environment resulted in a loss of tensile strength or ductility. A section of these specimens was also used for metallographic examination.

Stress corrosion tests were made by placing specimens in the peroxide solutions while under stress. The unwelded sheet specimens were bent to a 90° permanent bend over a smooth mandrel of a radius which was slightly greater than the recommended minimum bend radius for the particular alloy. The specimens were then sheared so that each leg was 3-1/2 inches long. After cleaning, the specimens were sprung into glass clamps having an internal span of 2-1/2 inches. The stressing was performed immediately before exposing the specimens to the peroxide solutions. Welded specimens were sprung into fixed deflection type glass jigs so that they were deformed an amount which would have produced a stress equal to 75% of the yield strength of the unwelded material if the material was uniformly deformed. The heat effect of the welding process caused the deformation to be non-uniform and the maximum stress probably was closer to the yield strength of the annealed material. The casting alloys were stressed by inserting them inside of 1-inch diameter heavy walled glass cylinders and tightening a take-up nut through an angle which was determined on calibration specimens using SR-4 strain gages. The stress corrosion jigs and specimens are shown in Figure 7.

Five of the alloys, 5652, 5254, 5086, 6363 and 6061, were given a sensitizing treatment by exposing them to 215°F for 30 days. Both unwelded and welded specimens were exposed to this treatment. The welded specimens were sensitized after welding. All sensitized specimens were exposed in the stressed condition using the fixed deflection type of jig.

In order to determine the effect of weld metal dilution on the corrosion characteristics of the 1260 cladding on a 5086 alloy backing, a 1-inch thick plate was welded as shown in Figure 1. The 1-inch thick material was chosen because this was the thickness which was recommended for the large tanks contemplated. The 5086 backing was machined off and the 0.060-inch thick welded cladding was exposed to the peroxide solutions.

Sloshing tests were conducted by fabricating rectangular containers, 2-1/2 inches by 2-1/2 inches by 9 inches long, from all of the sheet alloys except 5086. One end of each tank was welded with controlled 4043 rod and the remaining seams with parent metal. Two containers were made from the 5086 plate clad with 1260. These tanks were welded with a 1260 seal bead backed up with several passes of 5356 alloy. One of these containers was purposely made with a skip in the seal bead. The tanks were mounted on a rocking platform which rocked through an angle of 30° at a frequency of 25 cycles per minute. The tanks contained 200 cc of peroxide which was sufficient to fill them about half way.

The alloys were carefully segregated during the exposure to the peroxide solutions. Duplicate or triplicate specimens for a particular test were sometimes grouped in one container and individual containers were provided for others. During the course of the exposure the concentration of the peroxide was determined at intervals and the solution replaced whenever the concentration dropped below 85%.

TEST RESULTS AND DISCUSSION

General Appearance of Exposed Specimens

At the completion of the exposures to the peroxide solutions, representative specimens were photographed to record the extent of corrosion. These photographs are shown in Figures 8 through 22. A study of these photographs reveal several significant details. The presence of chloride in concentrations as low as 3 mg per liter (4.2 ppm) results in greatly accelerated corrosion in nearly all cases. The only exceptions being the two casting alloys B-214 and 43S in which the attack was only mildly accelerated. A number of the alloys which show little or no attack in the portion of the specimen which was immersed

in the 90% peroxide without additives were attacked by the vapor phase. The attack on welded specimens was in almost all cases localized in the heat affected zone some distance from the centerline of the weld outside the weld and fusion zones. This points to a heat sensitizing effect which is clearly evident in Figures 20 and 21. Figure 20 shows that the 6061 alloy was little affected by the liquid peroxide because the "sensitizing" treatment at 215°F was below the aging temperature. The heat affected zone of the welded specimen in Figure 21 was heated above the aging temperature which apparently sensitized this zone. The extensive vapor phase attack on the unwelded specimen is not present in the case of the welded specimen. Comparison of the stressed and unstressed specimens of the various alloys shows that macro stress is not necessary to initiate corrosion and does not accelerate it to any appreciable extent. The appearance of the 1260 cladding which was removed from the 5086 backing as shown in Figure 22 does not differ from the same alloy in sheet form as shown in Figure 9.

Tensile Tests

The ultimate tensile and yield strengths along with elongation were determined on both unexposed and exposed specimens. These tests were run in duplicate. The results may be found in Tables 1, 2, and 3. There is little evidence of deterioration of mechanical properties of any of the alloys due to exposure to the 90% H_2O_2 without additives. Even with the additives present the effects are minor with only small decreases in yield and ultimate strength occurring in some specimens and a general reduction in elongation due to notches caused by the corrosion pits. There are a number of cases where an increase in strength was found after the 6-month exposure to the peroxide without additives. This was probably due to a room temperature aging effect, the unexposed specimens being tested before the exposures were started. The temper of the 1260 cladding on the 5086 alloy was harder than the temper of the sheet material but as shown previously this did not alter the corrosion characteristics.

Intergranular Corrosion

The sections of the specimens and weldments that were examined for intergranular corrosion susceptibility in the peroxide solutions did not show any presence of this type of attack. A number of representative metallographic sections which were taken from various specimens are shown in Figures 23, 24, and 25. In general, the attack in both the liquid and vapor phases is a pitting type with penetration occurring by enlargement of sites at which the attack is initiated without preference for grain boundaries. The deep pitting at localized sites is evidence that the corrosion is assisted by galvanic action rather than being just chemical solution of the metal. Two of the photomicrographs have different characteristics which are worthy of note, 24 (a) and 24 (f). Figure 24 (a) shows the general corrosion

which occurred between pits on a specimen of alloy 1060. A general decrease in thickness was apparent over wide areas of this specimen indicating a chemical solution of the metal between the deeper pits which had the same characteristics shown in the other photomicrographs. Figure 24 (f) shows the type of attack on the cast alloy 356. This appears to be an oxidation of the eutectic constituent by the peroxide rather than a dissolution of it.

Stress Corrosion

There were no stress corrosion failures in any of the specimens exposed for this type of test. The stress corrosion test fixtures used were previously discussed and are shown in Figure 7. All but the preformed stress corrosion test specimens are shown in Figures 8 through 22. The preformed stress corrosion specimens are shown in Figures 26 and 27. It appears in these latter photographs that cold work may accelerate the general corrosion of the 5254 and 1060 alloys in the presence of chlorides. The corrosion appears to have initiated at the bend and along the machined edges of these specimens. Cold work is often responsible for setting up a galvanic corrosion cell in many solutions. It is to be emphasized that there were no stress corrosion failures in this test program.

Sloshing Tests

At the completion of the 6-month sloshing tests during which the 2-1/2-inch by 2-1/2 inch by 9-inch tanks were continuously rocked back and forth while half filled with 90% H_2O_2, the tanks were sawed lengthwise to expose the interior. Photographs were taken of all the tanks and these are shown in Figures 28 through 31. The interior surface of all tanks was bright and uncorroded with the exception of the one made of 6061 alloy which had a frosty discolored surface and some light corrosion of the parent metal welds as shown in Figure 31. There was also some discoloration of the 43S welds in the 6363 alloy tank. It was expected that some corrosion might occur in the 1260 clad 5086 tank where a discontinuity had been left in the 1260 seal bead exposing the 5086 alloy to attack in a localized area. Figure 32 shows that this did not occur. There was no chloride added to the 90% peroxide used in the sloshing tests. The presence of chloride would undoubtedly cause destructive attack as it did in the other specimens.

Decomposition of Peroxide

The suitability of a particular alloy for use with 90% hydrogen peroxide storage is dependent upon two important factors: (1) The corrosion rate of the alloy when in contact with the peroxide under storage conditions, and (2) the rate of decomposition of the peroxide when in contact with the alloy under these conditions. In order to obtain a good correlation between the corrosion data and peroxide

behavior, periodic checks were made on the peroxide concentration. Whenever it was found that the concentration had fallen below 85%, the solution was replaced with fresh 90% solution. The records of peroxide concentration are shown graphically in Figures 33 through 47. It is apparent that the chloride containing solutions were subject to decomposition at a much faster rate than those without additives. It is not meant to imply that the chloride causes the decomposition but the increased surface area due to corrosion and the resulting corrosion products are probably responsible. In general, those alloys which showed the best resistance to corrosion also caused the least decomposition of the peroxide.

If the alloys which were exposed to the peroxide without chloride additions are examined closely, one finds very little corrosion occurring except in the vapor phase. Grouping these specimens according to the amount of corrosion results in the following order of increasing attack: (1) 3003 (2) 5086 (3) 1100 (4) 6061 (5) 5254 (6) 6363 (7) 5652 (8) 1260 (9) 1060. A regrouping of the alloys results if the specimens exposed to the solution with chloride-nitrate additions are considered: (1) 5254 (2) 5652 (3) 3003 (4) 5086 (5) 6363 (6) 1060 (7) 6061 (8) 1100 (9) 1260.

As pointed out previously, the decomposition of the peroxide is an important factor to consider. Examination of the curves in Figures 33 through 47 allows one to rate the alloys qualitatively according to rate of peroxide decomposition as follows:

In the solution without additives: (1) 6061 (2) 3003 (3) 1100 (4) 5254 (5) 5652 (6) 5086 (7) 6363 (8) 1260 (9) 1060.

In the solution with additives: (1) 5254 (2) 6061)3) 5086 (4) 6363 (5) 5652 (6) 3003 (7) 1100 (8) 1060 (9) 1260.

An estimate of the relative order of the alloys when both the presence of chloride and the decomposition of the peroxide are considered can be obtained by adding the integers which designate the relative orders of the alloys as given above. If this is done, the following order results: (1) 5254 (2) 3003 (3) 6061 (4) 5086 (5) 5652 (6) 6363 (7) 1060 (8) 1100 (9) 1260. This is only an indication of the relative order and not too much weight can be given to the placement of the individual alloys. However, three distinct groupings can be made in order of decreasing compatibility of alloys which are roughly equivalent when all factors are considered:

(1) 5254, 3003
(2) 5086, 6061, 5652
(3) 6363, 1060, 1100, 1260

The cast alloys can be analyzed in the same manner with much less difficulty and the following relative order of preference for peroxide service established: (1) B-214 (2) 43S (3) 356.

It is important to keep in mind that only one heat of each alloy is represented in these tests and that variations in chemical composition and temper within commercial tolerances could cause changes in the test results.

CONCLUSIONS

Although a number of conclusions can be drawn from the data which were obtained during the course of this test program, they must be considered in the light of the fact that some of the results could be altered by minor changes in alloy composition and temper.

1. The most general conclusion that can be drawn is that even small concentrations of chloride, as low as 2 mg/liter, cause a marked increase in the corrosion rate.

2. The results of the tensile tests and metallographic examination reveal no evidence of intergranular attack.

3. The alloys tested are not susceptible to stress corrosion under the test conditions and solutions used.

4. Localized cold work appears to accelerate mildly the corrosive attack in the 5254 and 1060 alloys.

5. The corrosion rate for 5652, 5254, 5086 and 6363 is greatly accelerated by prolonged heating at 215°F. Alloy 6061 will be sensitized by heating to higher temperatures. The remaining alloys were not given a sensitizing treatment.

6. Sloshing has little effect on accelerating the corrosion rate of 90% peroxide without additives.

7. Discontinuities in the 1260 seal bead on welded clad 5086 alloy do not result in increased localized corrosion in 90% peroxide without additives.

8. The chloride containing solutions decomposed at a faster rate than those without chloride. This is also a function of the greater amount of corrosion which occurred in the chloride containing solutions.

9. Those alloys which showed the best resistance to corrosion also caused the least decomposition of the peroxide.

10. The wrought alloys tested can be grouped into three groups in order of decreasing compatibility as follows:

(1) 5254, 3003
(2) 5086, 6061, 5652
(3) 6363, 1060, 1100, 1260

11. The cast alloys rank in the following relative order:

(1) B-214
(2) 43S
(3) 356

RECOMMENDATIONS

It is recommended that additional work be carried out to define the effects of variations in chemical composition and rolling temper within commercial tolerances and that the nature of the corrosive attack be studied to arrive at a better understanding which could possibly lead to the development of special alloys for peroxide service.

TABLE 1

MECHANICAL PROPERTIES OF ALUMINUM SHEET ALLOYS BEFORE AND AFTER EXPOSURE TO 90% H_2O_2 WITH AND WITHOUT ADDITIVES

Alloy	Unexposed to H_2O_2 Yield Strength PSI	Unexposed to H_2O_2 Ultimate Tensile Strength PSI	Unexposed to H_2O_2 Elongation %	Exposed H_2O_2 No Additives Yield Strength PSI	Exposed H_2O_2 No Additives Ultimate Tensile Strength PSI	Exposed H_2O_2 No Additives Elongation %	Exposed H_2O_2 + Cl + NO_3* Yield Strength PSI	Exposed H_2O_2 + Cl + NO_3* Ultimate Tensile Strength PSI	Exposed H_2O_2 + Cl + NO_3* Elongation %
1100	16,670	18,140	6.5	17,790	19,390	6.5	15,920	18,090	6.5
"	15,440	18,100	6.	17,810	19,500	6.	15,780	18,090	7.5
1260	5,160	9,950	29.	7,260	8,200	26.	7,460	12,150	33.5
"	5,400	9,740	27.5	7,120	8,350	22.	6,960	11,650	30.0
3003	19,400	21,700	7.5	21,100	22,800	6.	19,250	20,900	4.
"	19,150	22,100	7.	21,100	22,900	4.	18,850	20,900	5.
5652	29,700	31,650	8.	32,000	37,600	9.	30,400	33,200	3.5
"	32,500	38,200	9.	29,900	38,300	9.	31,100	35,500	5.
1060	12,460	13,340	11.5	12,110	16,710	10.5	11,720	14,990	5.
"	11,880	13,810	11.	12,980	15,450	10.	13,100	14,720	4.5
5254	31,700	37,000	5.5	29,700	41,000	11.5	30,200	36,700	5.5
"	31,500	40,700	8.	30,100	41,100	13.	34,500	42,900	8.
6363	22,100	24,700	7.	20,100	24,700	8.5	18,850	22,100	3.
"	19,950	20,690	5.	19,850	25,500	8.5	17,280	20,100	2.5
6061	44,300	52,700	11.	41,400	46,900	13.	41,200	44,700	5.
"	42,900	47,700	11.5	42,400	47,100	13.	41,100	43,300	8.5
5086	36,100	46,600	10.	35,500	48,400	11.	34,000	47,200	8.5
"	36,699	46,400	10.	36,800	48,600	10.	38,100	48,400	9.5
1260	12,300	17,600	8.5						
(Cladding)	12,100	18,100	8.						

*90% H_2O_2 + 3 mg/l Cl + 4 mg/l NO_3

TABLE 2

MECHANICAL PROPERTIES OF WELDED ALUMINUM SHEET ALLOYS BEFORE AND AFTER EXPOSURE TO 90% H_2O_2 WITH AND WITHOUT ADDITIVES

Alloy	Unexposed to H_2O_2			Exposed H_2O_2 No Additives			Exposed H_2O_2 + Cl + NO_3*		
	Yield Strength PSI	Ultimate Tensile Strength PSI	Elongation %	Yield Strength PSI	Ultimate Tensile Strength PSI	Elongation %	Yield Strength PSI	Ultimate Tensile Strength PSI	Elongation %
1100	13,100	15,710	12.5	11,960	15,100	14.	10,040	11,890	8.
"	13,000	16,600	14.	11,960	15,150	14.	10,350	12,740	14.
1260	9,740	12,980	10.5	9,490	11,220	12.	7,610	9,730	9.5
"	10,270	12,840	11.	9,220	11,500	10.	7,860	9,740	11.
3003	9,490	15,730	11.	10,320	15,350	9.5	12,040	16,300	11.5
"	12,810	16,640	11.5	12,340	16,700	9.5	14,210	18,100	11.
5652	27,600	31,200	6.5	25,700	29,700	11.	23,800	27,500	7.
"	26,900	32,500	7.	27,100	32,300	8.	24,500	28,400	9.
1060	7,700	11,520	8.	9,760	11,460	7.5	11,110	13,340	15.
"	9,030	12,750	7.	10,370	11,290	7.	9,500	11,700	10.
5254	26,500	32,100	9.5	25,500	33,600	9.	23,659	30,500	6.
"	26,700	33,245	8.5	22,390	28,800	7.**	26,100	30,500	7.5
6363	23,400	27,500	7.	21,500	24,300	6.	16,220	18,820	4.
"	23,800	28,000	6.5	21,100	23,090	6.5	16,810	19,600	4.5
6061	24,900	26,700	4.	27,100	28,600	4.	23,400	27,700	4.5
"	27,400	28,300	4.	27,300	28,700	4.	23,600	25,900	4.5
5086	33,330	43,600	8.	35,000	38,100	7.	29,200	40,300	24.
"	32,700	46,400	8.5	32,200	43,800	10.	28,300	41,300	23.

*90% H_2O_2 + 3 mg/l Cl + 4 mg/l NO_3

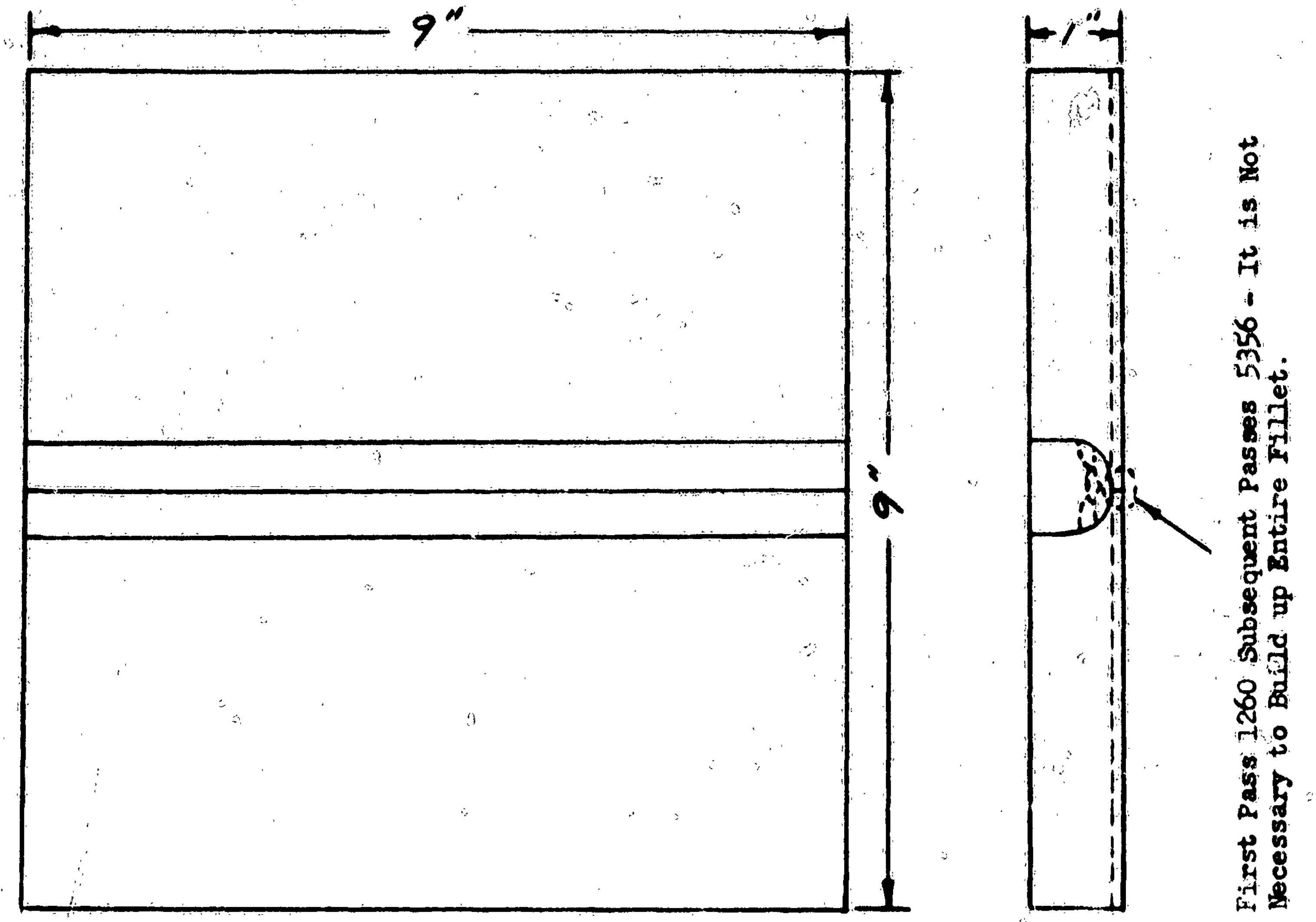
**Fractured in Weld

TABLE 3

MECHANICAL PROPERTIES OF CAST ALUMINUM ALLOYS IN THE AS-CAST AND WELDED CONDITIONS BEFORE AND AFTER EXPOSURE TO 90% H_2O_2 WITH AND WITHOUT ADDITIVES

Alloy	Unexposed to H_2O_2 Yield Strength PSI	Unexposed to H_2O_2 Ultimate Tensile Strength PSI	Unexposed to H_2O_2 Elongation %	Exposed H_2O_2 No Additives Yield Strength PSI	Exposed H_2O_2 No Additives Ultimate Tensile Strength PSI	Exposed H_2O_2 No Additives Elongation %	Exposed H_2O_2 + Cl + NO_3* Yield Strength PSI	Exposed H_2O_2 + Cl + NO_3* Ultimate Tensile Strength PSI	Exposed H_2O_2 + Cl + NO_3* Elongation %
356-F	12,410	28,500	2.5	20,800	28,500	8.	17,460	31,300	6.
"	13,020	29,900	4.	16,240	25,900	6.	16,890	29,300	4.5
43-F	11,050	21,300	5.0	12,860	22,100	4.	12,860	22,100	4.5
"	13,020	22,100	5.5	10,040	19,810	4.	9,740	21,700	5.
B214-F	13,190	27,100	5.5	18,110	25,700	11.	23,700	25,200	9.
"	11,760	25,700	6.5	22,700	31,600	9.	19,100	22,500	10.5
356 (Welded)	11,460	19,550	2.	15,750	20,700	10.	13,650	20,790	6.5
"	11,980	20,300	2.5	12,550	16,650	6.	12,710	19,350	6.
43 (Welded)	10,340	19,190	5.5	9,090	18,960	14.	9,740	19,350	10.
"	10,340	18,290	6.5	11,020	17,480	9.5	10,790	18,250	11.
B214 (Welded)	10,150	19,000	3.0	15,590	18,500	5.	15,980	23,900	4.5
"	10,420	20,100	3.5	16,890	20,900	2.**	13,130	22,100	4.

*90% H_2O_2 + 3 mg/l Cl + 4 mg/l NO_3
**Unsound Weld



Test Plate
(1260 Clad on 5086)

Tensile and Stress Corrosion Specimens Will be Made as Follows:

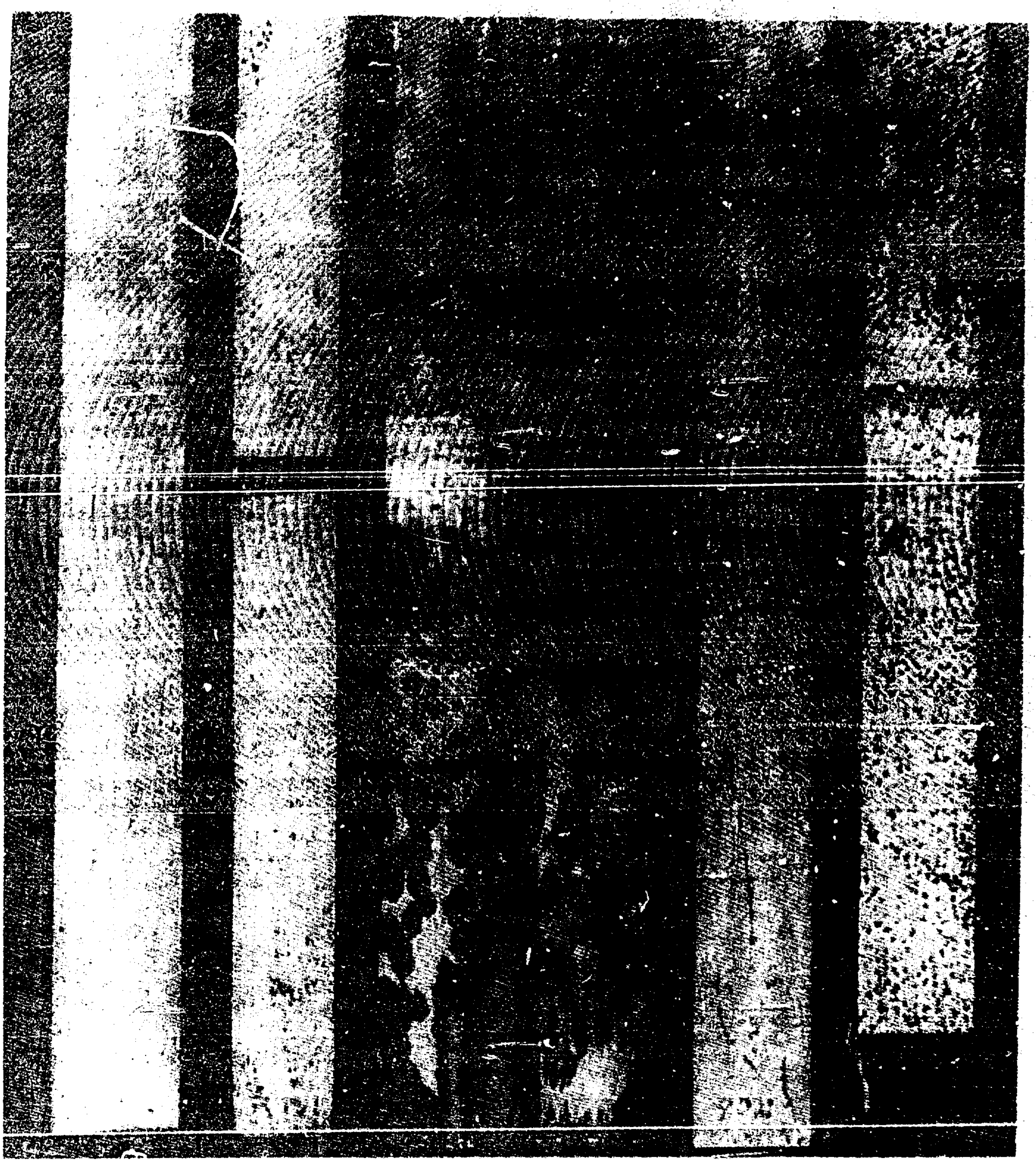
1) Penetration of first pass removed flush with surface.
2) Plate cut into 1-inch wide strips with weld at center.
3) Strips press straightened.
4) 15/16 inch metal removed from 5086 side.

Test specimens will represent 1260 face on one side and alloy dilution at 1/16 inch below surface.

Figure 1 Method of Preparation for Specimens of 1260 Alloy Cladding

5652 1060 5254

Figure 3 SPECIMENS OF ALLOYS 5652, 1060 AND 5254 AFTER 24 HOURS EXPOSURE TO 90% H_2O_2 CONTAINING 20 ppm ADDED CHLORIDES



6363 6061 5086

Figure 4 SPECIMENS OF ALLOYS 6363, 6061 AND 5086 AFTER 24 HOURS EXPOSURE TO 90% H_2O_2 CONTAINING 20 ppm ADDED CHLORIDES

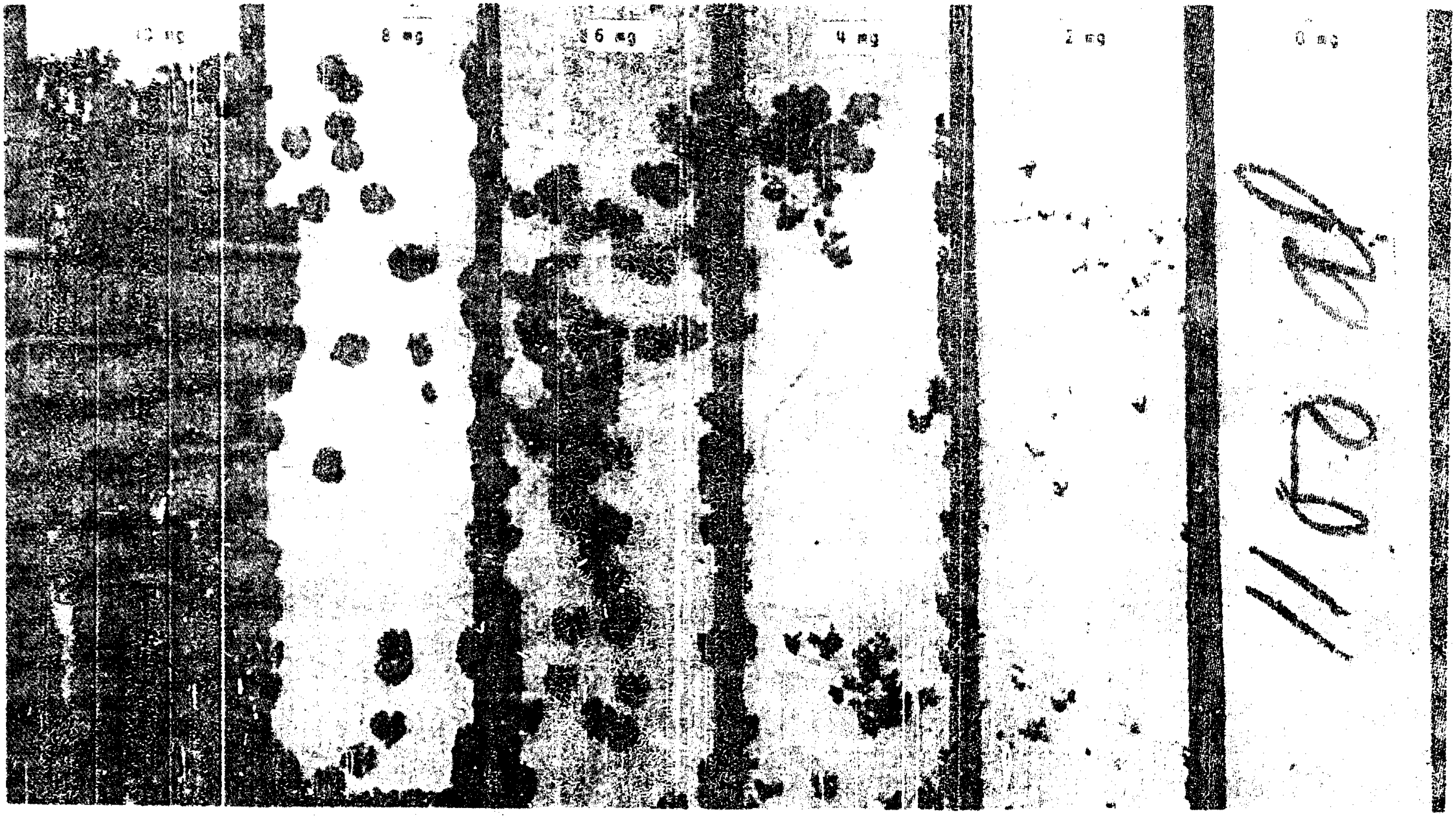


Figure 5 SPECIMENS OF ALLOY 1100 AFTER 7 DAYS EXPOSURE TO 90% H_2O_2 CONTAINING VARIOUS CONCENTRATIONS OF CHLORIDE ION

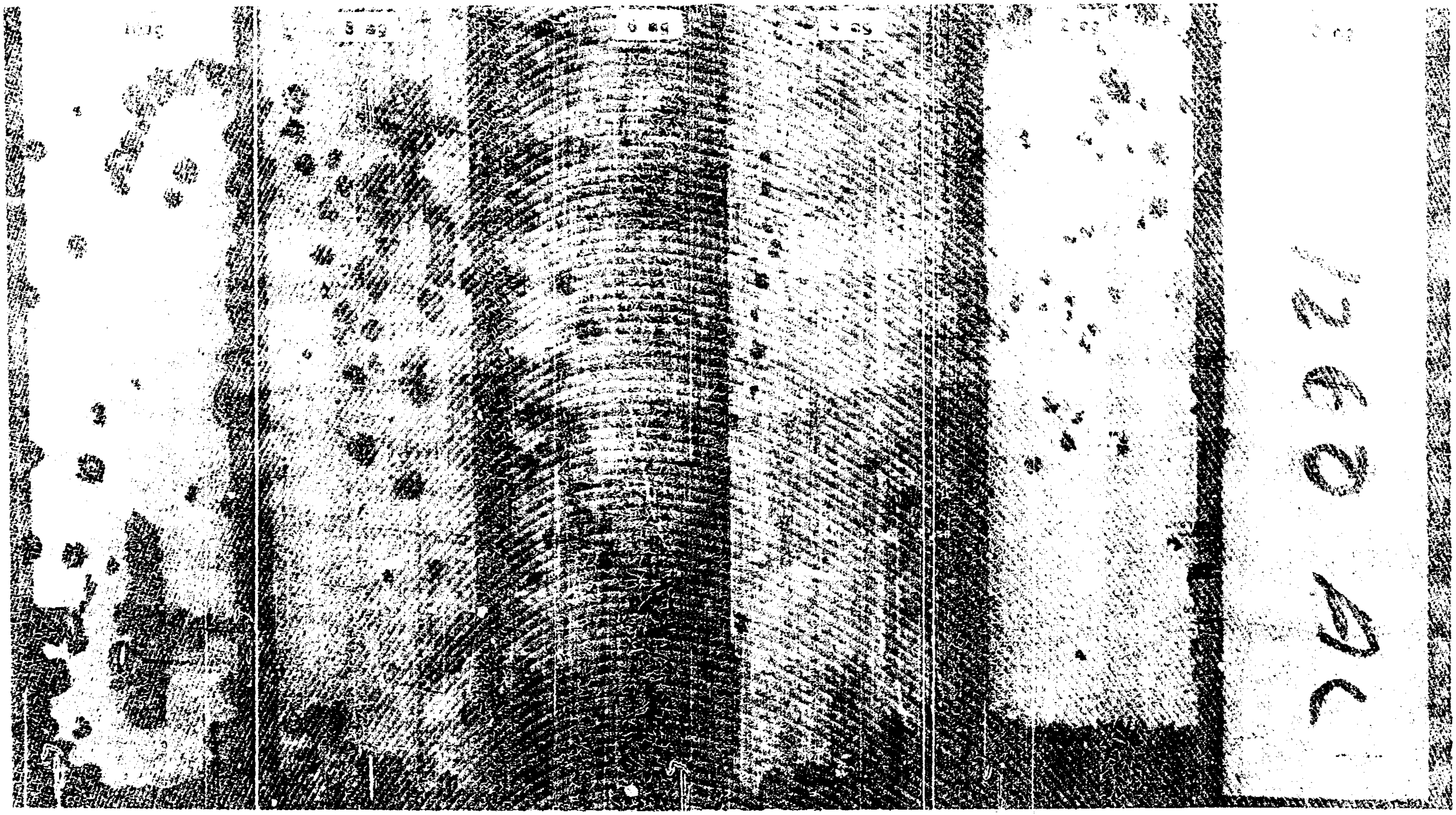


Figure 6 SPECIMENS OF ALLOY 1260 AFTER 7 DAYS EXPOSURE TO 90% H_2O_2 CONTAINING VARIOUS CONCENTRATIONS OF CHLORIDE ION

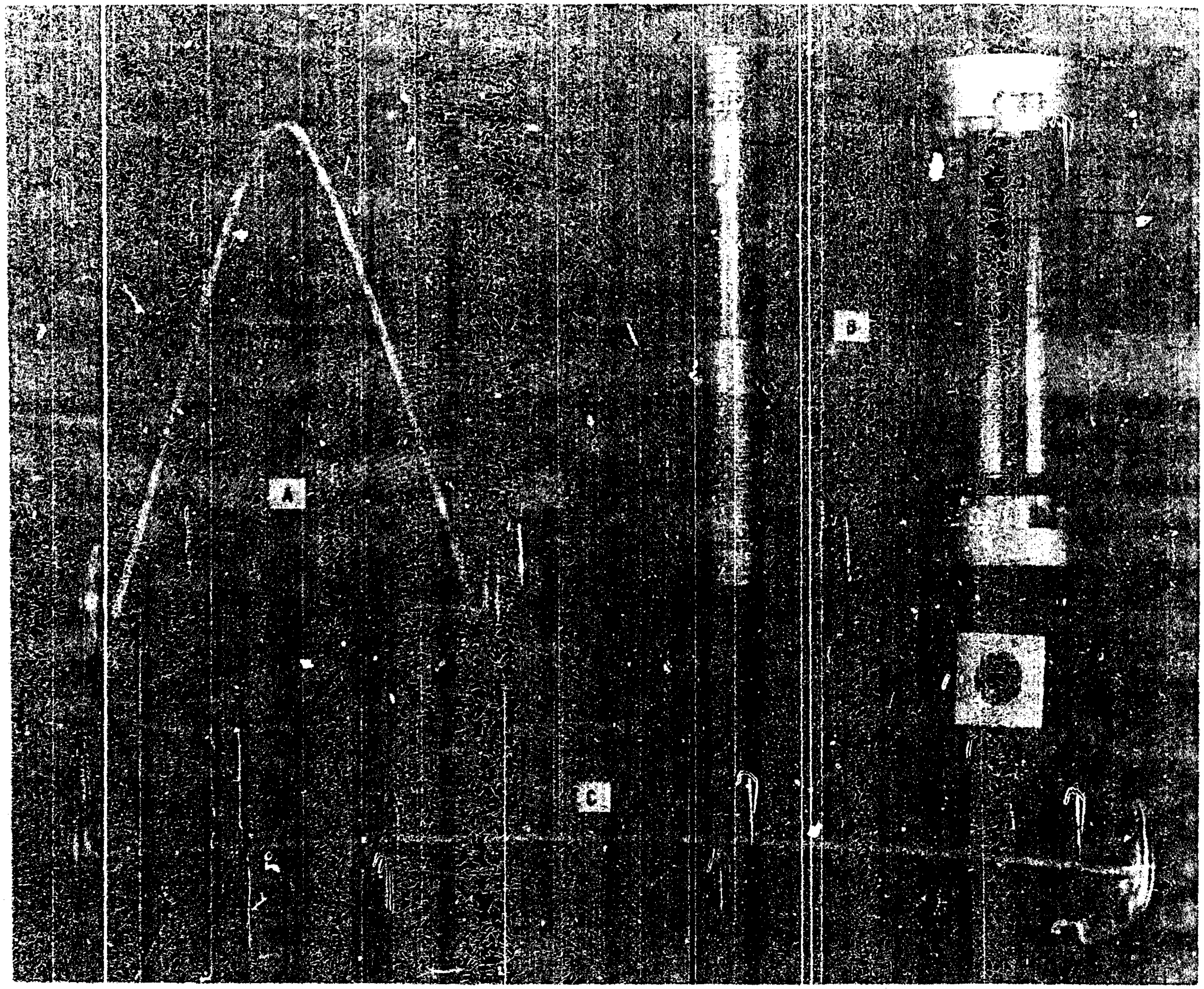
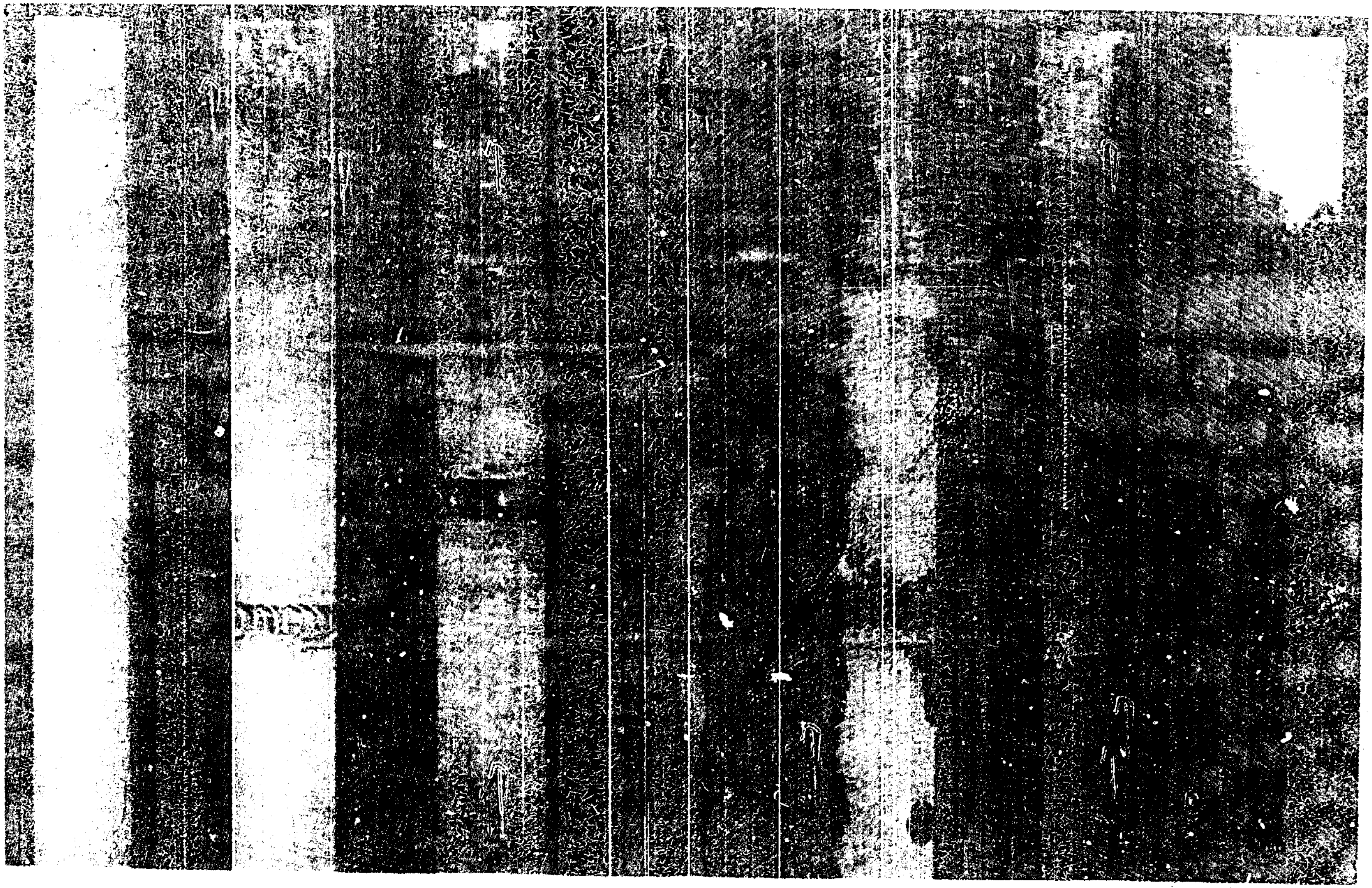


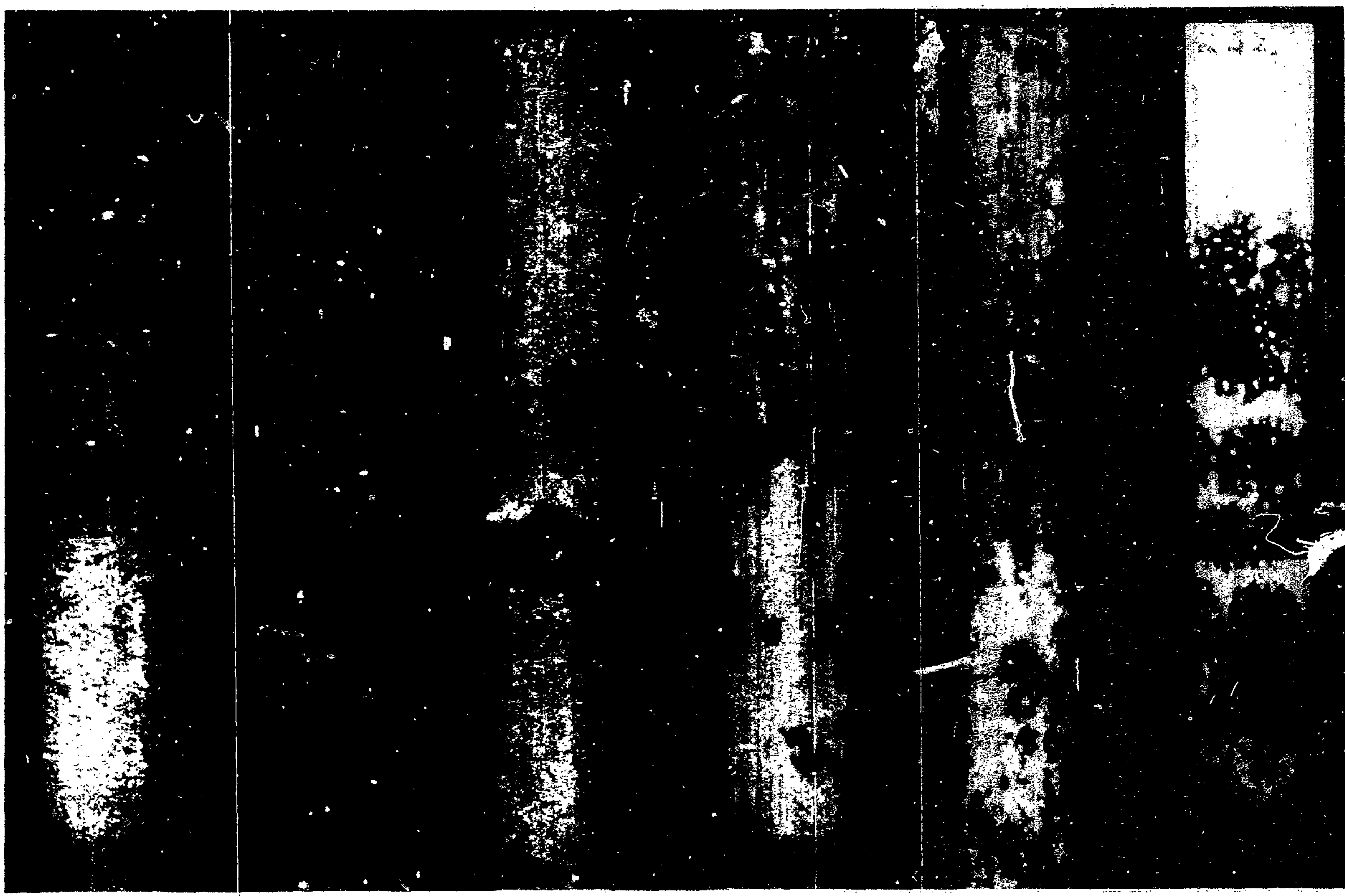
Figure 7 STRESS CORROSION SPECIMENS AND GLASS JIGS: (A) SHEET SPECIMENS (B) CAST SPECIMENS (C) WELDED AND "SENSITIZED SPECIMENS"



MO. | 6 MO. | (STRESSED) 6 MO. | 7 DAYS | 44 DAYS | 4 MO. | (STRESSED) 61 DAYS

← 90% H_2O_2, NO ADDITIVES → ← 90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3 →

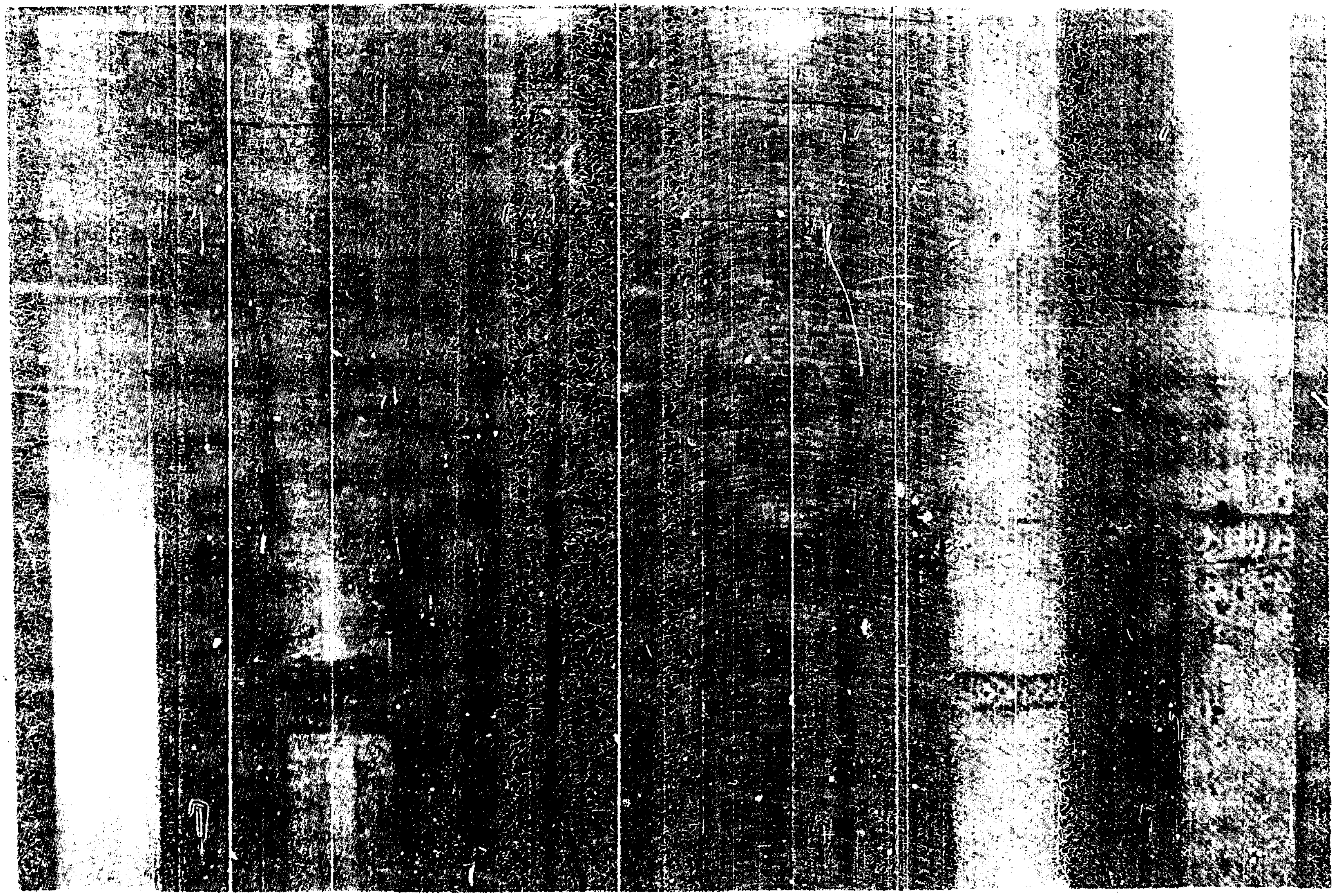
Figure 8 SPECIMENS ALUMINUM ALLOY 1100



6 MO.	6 MO.	(STRESSED) 6 MO.	7 DAYS	44 DAYS	(STRESSED) 61 DAYS

← 90% H_2O_2 - NO ADDITIVES → ← 90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3 →

Figure 9 SPECIMENS ALUMINUM ALLOY 1260



(STRESSED) (STRESSED)

6 MO. 6 MO. 6 MO. 30 DAYS 6 MO. 6 MO.

← 90% H_2O_2 NO ADDITIVES → ← 90% H_2O_2 + 3 mg/ℓ Cℓ AND [illegible] mg/ℓ NO_3 →

Figure 10 SPECIMENS ALUMINUM ALLOY 3003

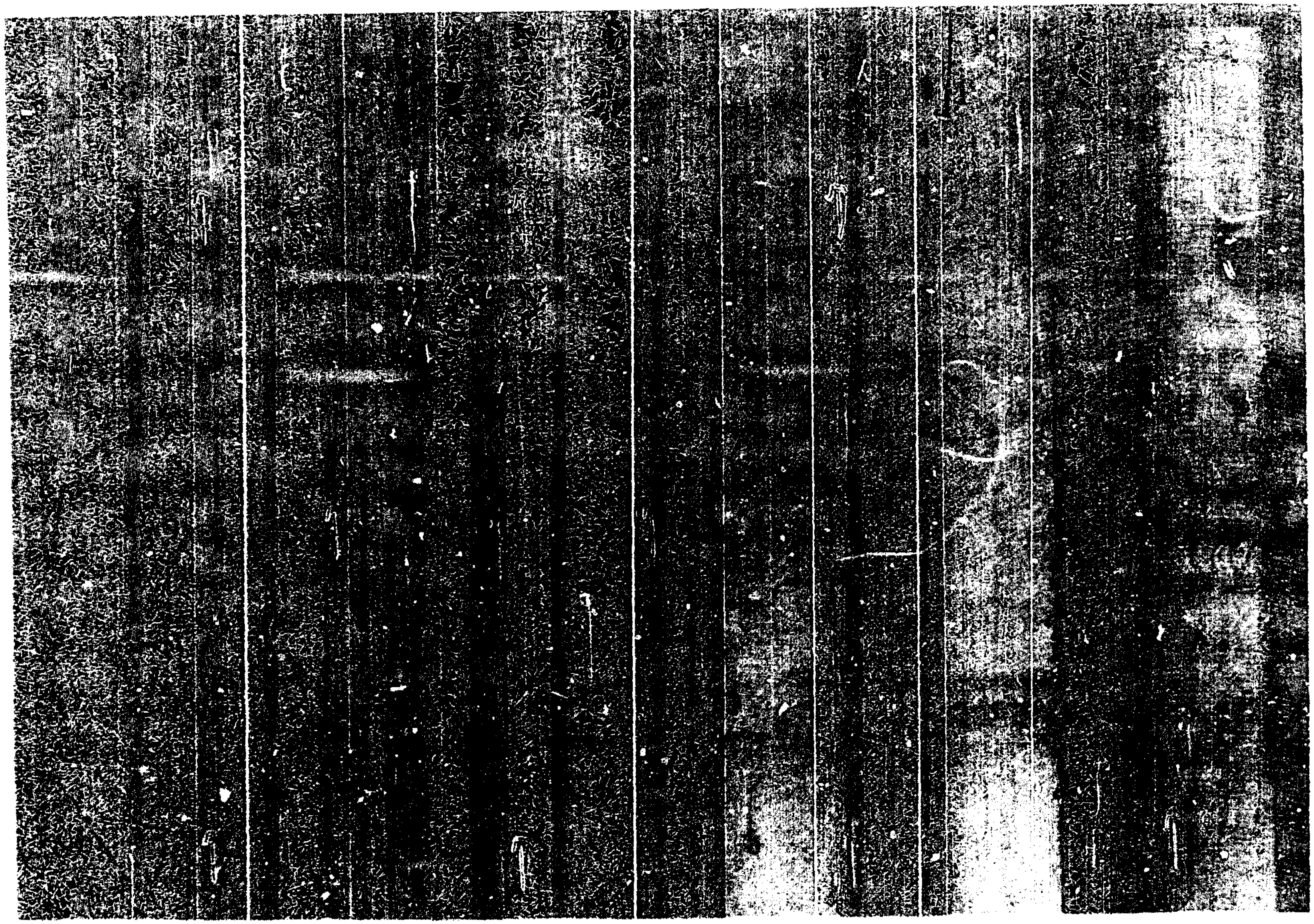
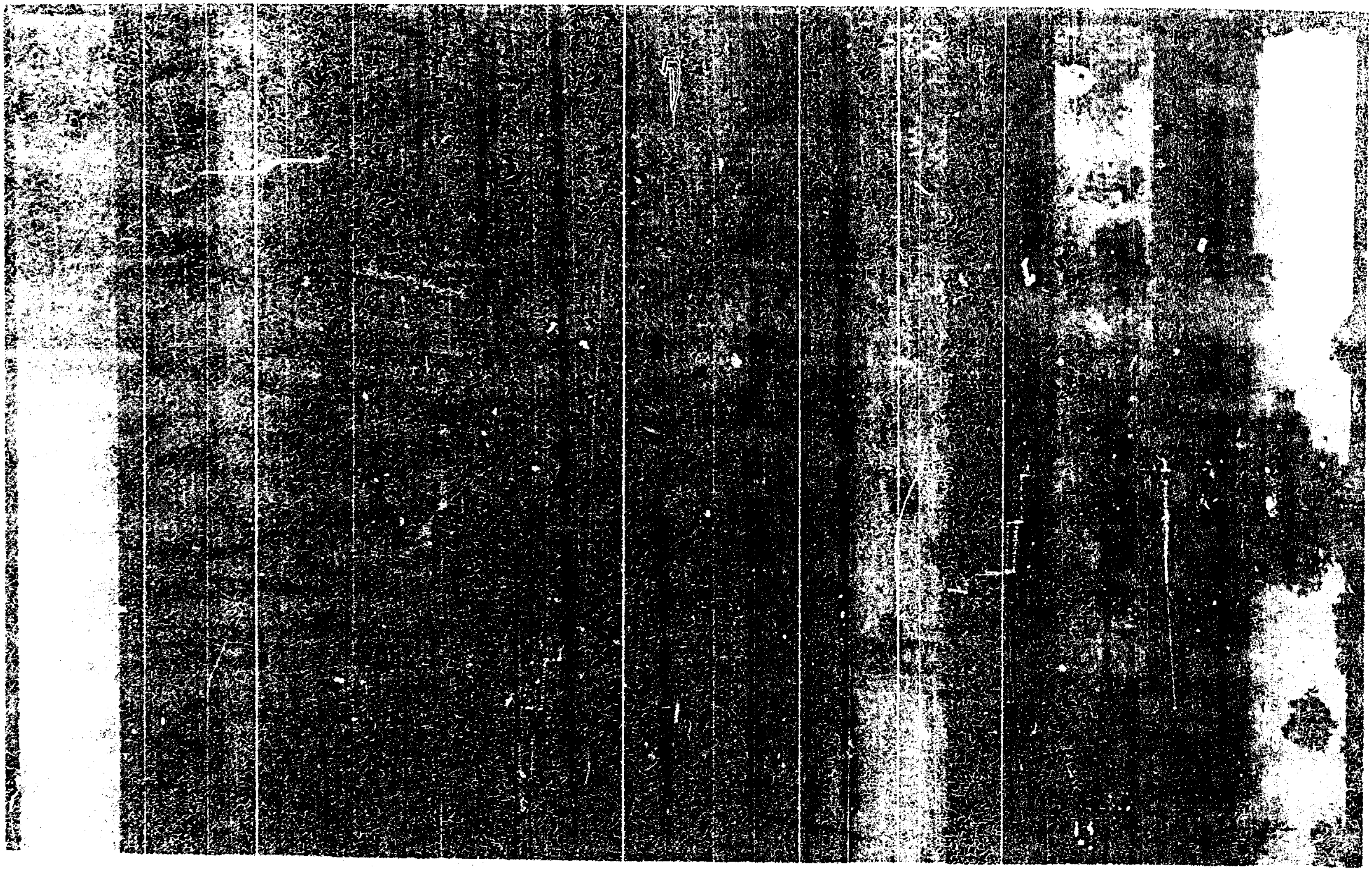


Figure 11 SPECIMENS ALUMINUM ALLOY 5652



6 MO. ← 90% H_2O_2 - NO ADDITIVES → 6 MO. (STRESSED) 6 MO.

36 DAYS ← 90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3 → 44 DAYS 6 MO. (STRESSED) 90 DAYS

Figure 12 SPECIMENS ALUMINUM ALLOY 1060

6 MO | 6 MO. | (STRESSED) 6 MO. | 36 DAYS | 6 MO. | 6 MO. | (STRESSED) 6 MO.

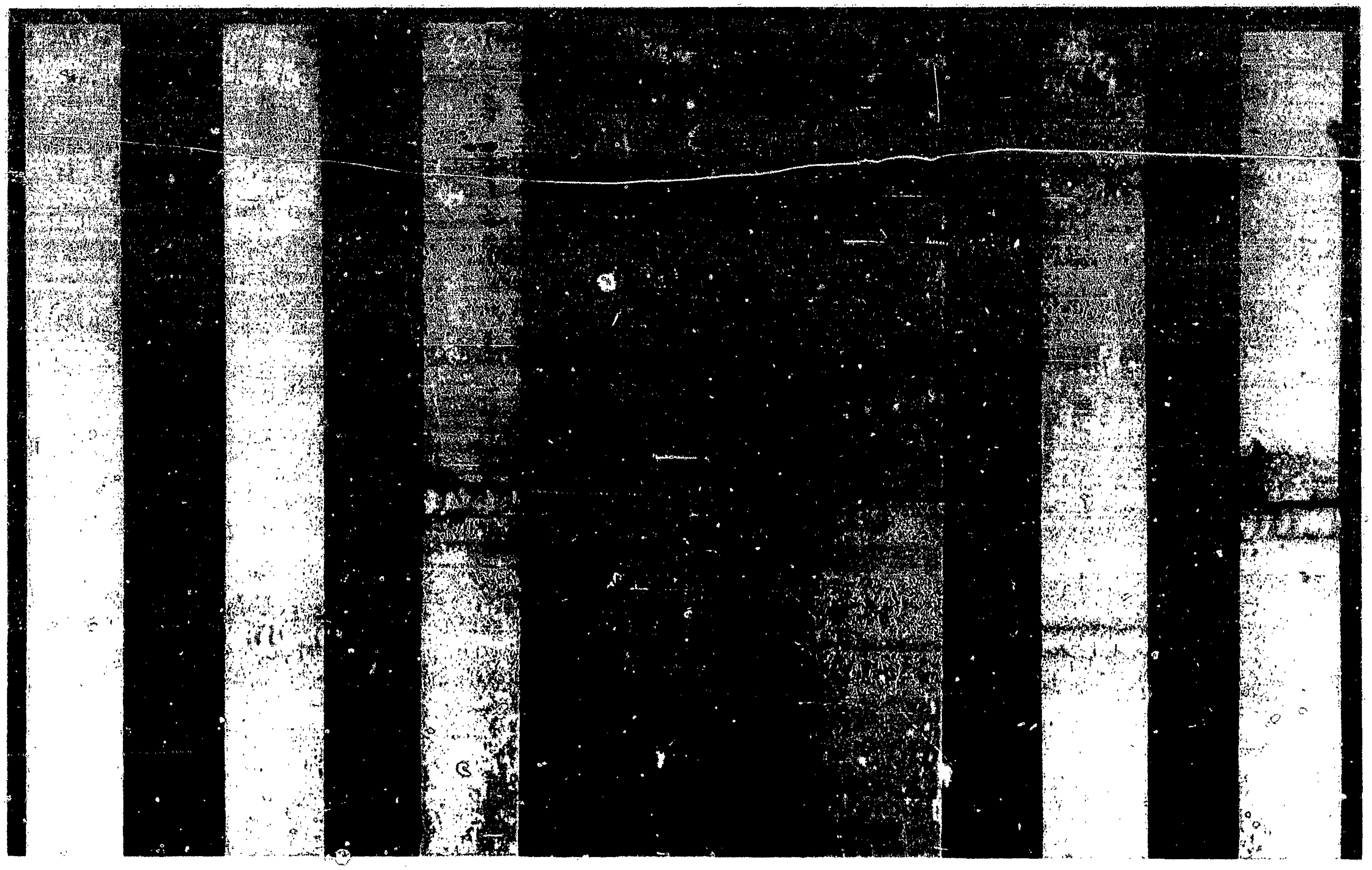
← 90% H_2O_2 - NO ADDITIVES → ← 90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3 →

Figure 13 SPECIMENS ALUMINUM ALLOY 5254

6 MO.	6 MO.	(STRESSED) 6 MO.	36 DAYS	6 MO.	(STRESSED) 6 MO.
← 90% H_2O_2 - NO ADDITIVES →			← 90% H_2O_2 + 3 mg/ℓ Cℓ AND [illegible] mg/ℓ NO_3 →		

Figure 14 SPECIMENS ALUMINUM ALLOY 6363

Figure 5 SPECIMENS ALUMINUM ALLOY 6061



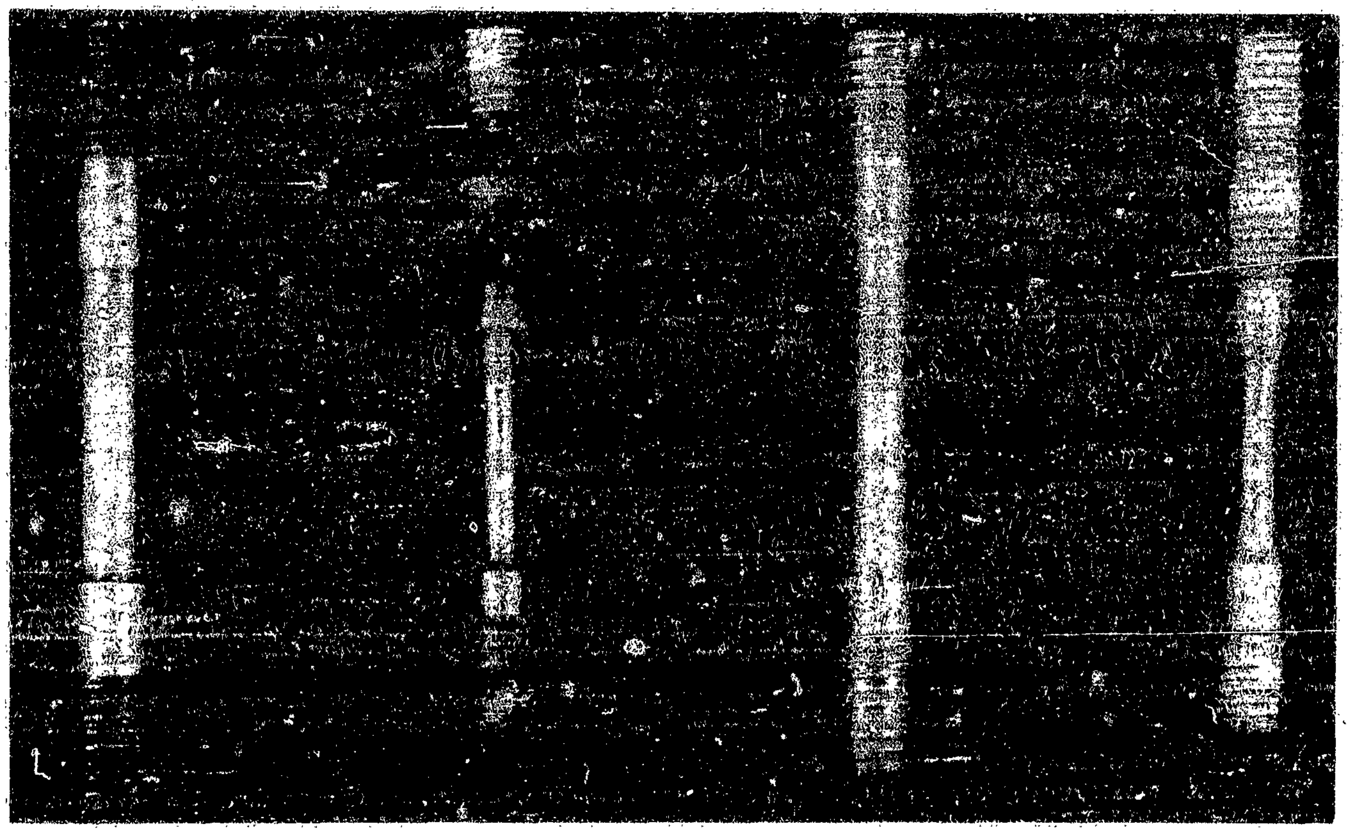
6 MO. 6 MO. (STRESSED) 6 MO.

← 90% H_2O_2 - NO ADDITIVES →

7 DAYS 77 DAYS 6 MO. (STRESSED) 6 MO.

← 90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3 →

Figure 16 SPECIMENS ALUMINUM ALLOY 5086



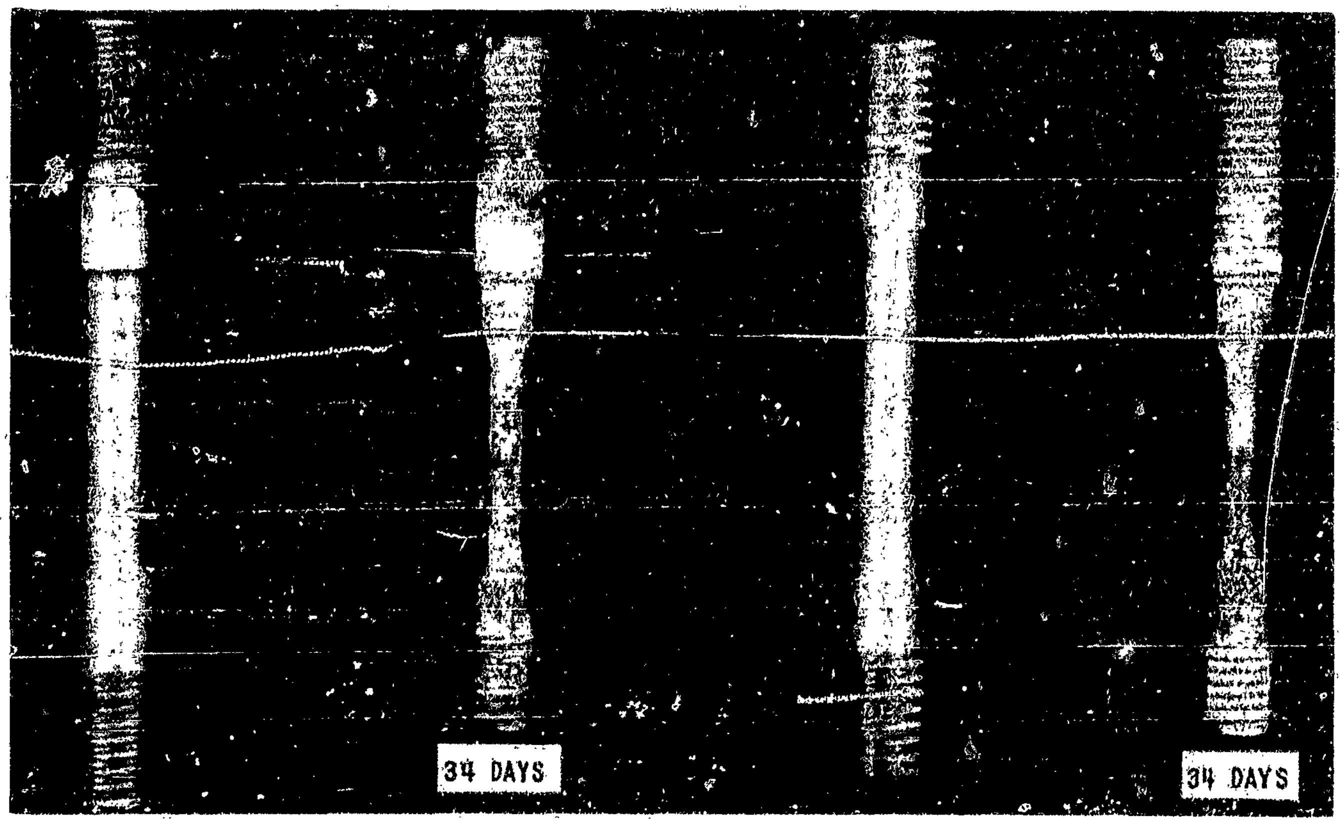
AS-CAST

UNSTRESSED STRESSED

WELDED

UNSTRESSED STRESSED

90% H_2O_2- NO ADDITIVES



AS-CAST

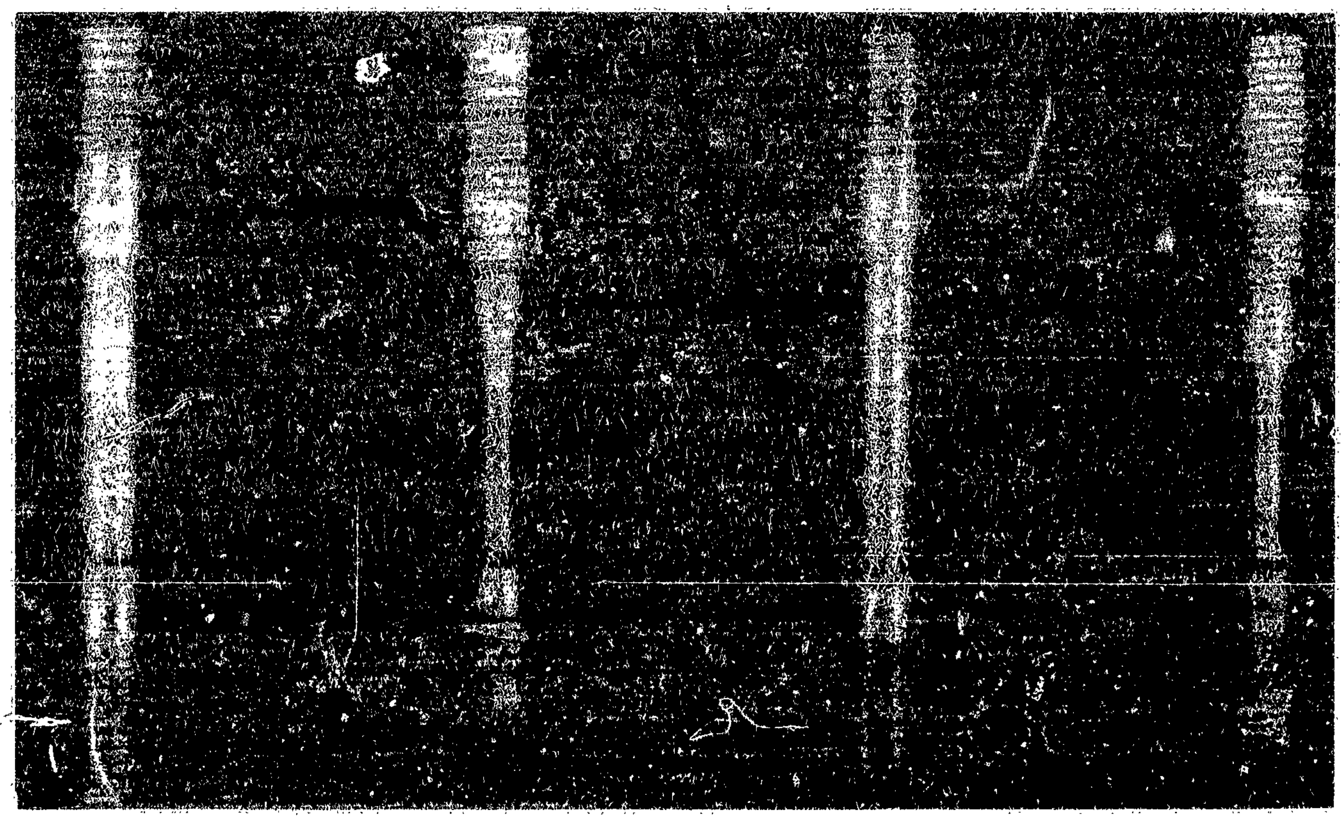
UNSTRESSED STRESSED

WELDED

UNSTRESSED STRESSED

90% H_2O_2- + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3

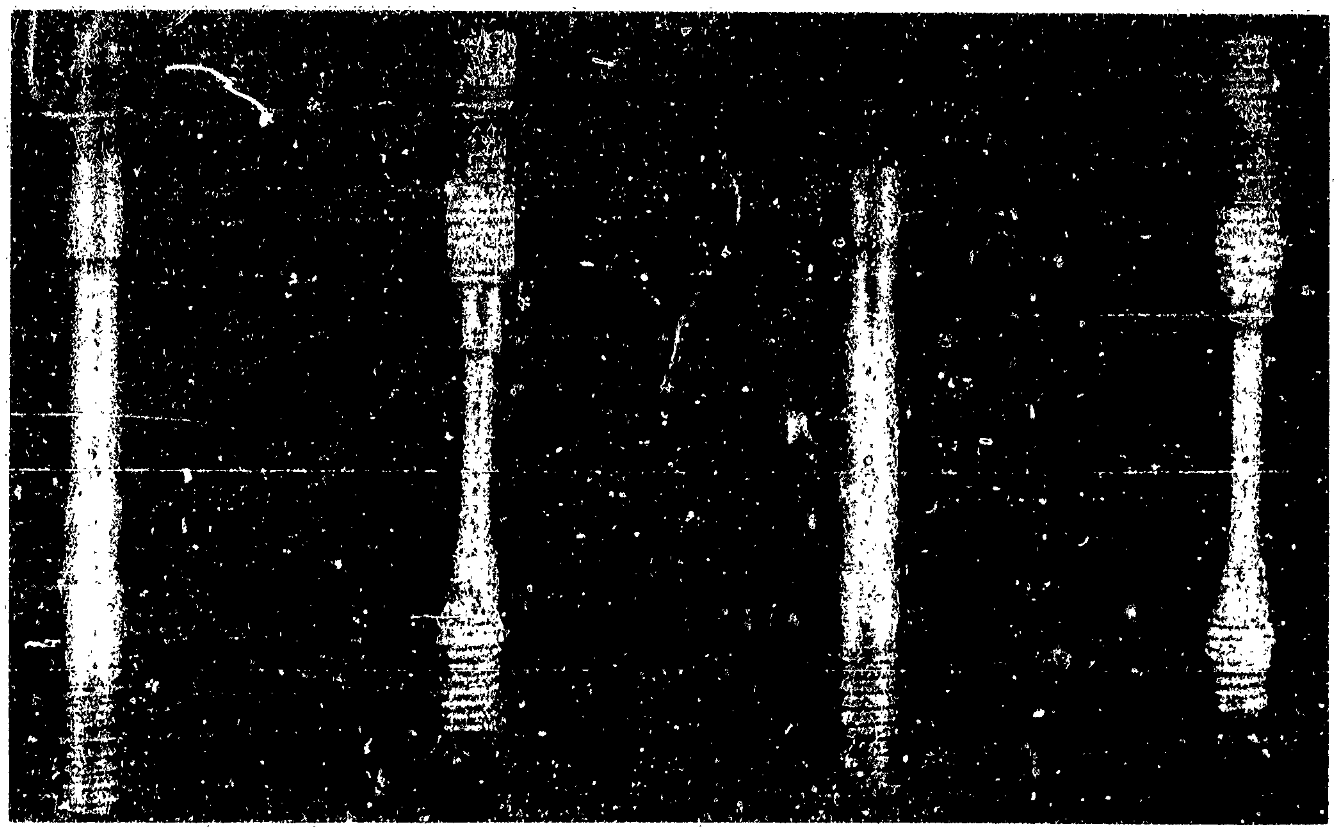
Figure 17 SPECIMENS OF CASTING ALLOY 356
(ALL EXPOSURES 6 MONTHS EXCEPT AS NOTED)



AS-CAST WELDED

UNSTRESSED STRESSED UNSTRESSED STRESSED

90% H_2O_2- NO ADDITIVES

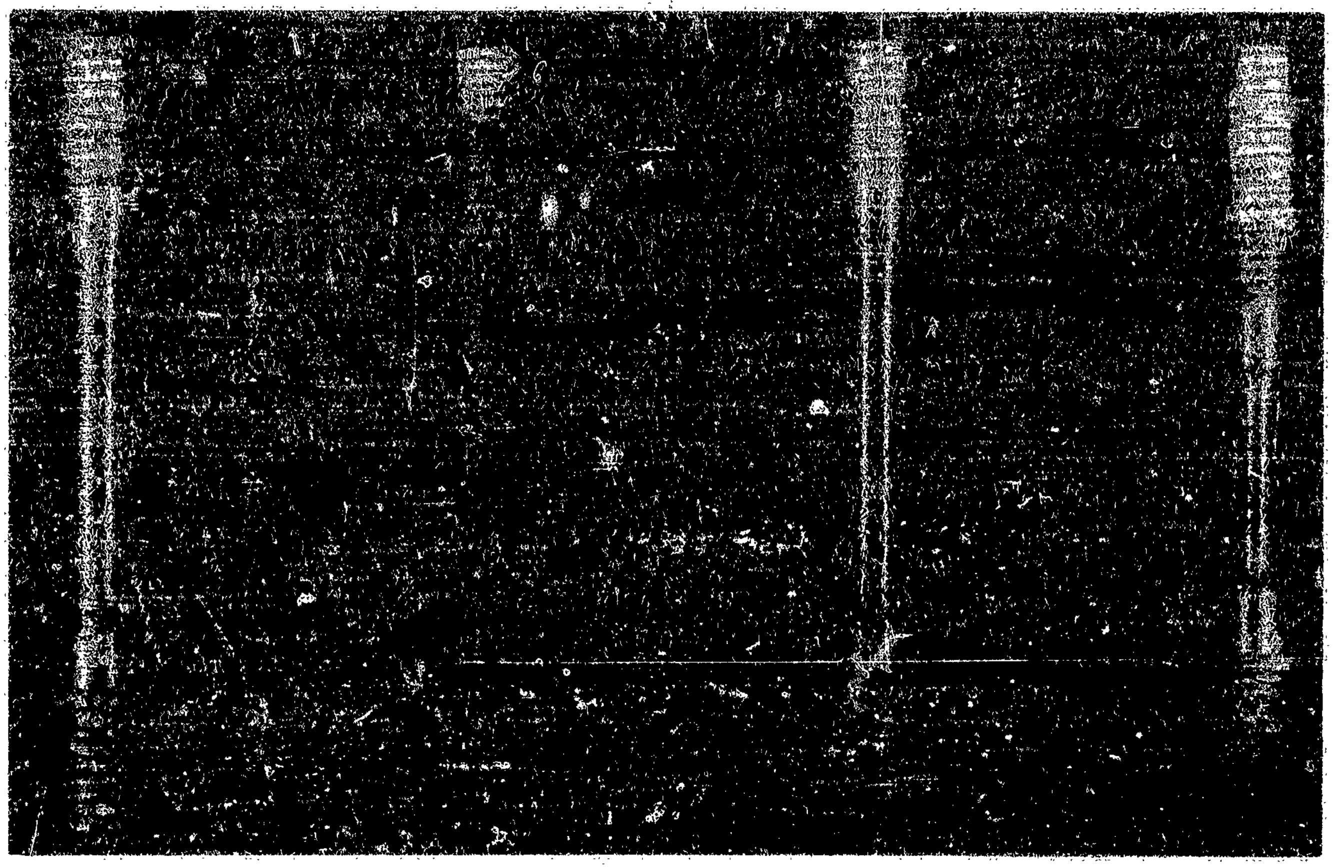


AS-CAST WELDED

UNSTRESSED STRESSED UNSTRESSED STRESSED

90% H_2O_2+3 mg/ℓ $C\ell$ AND 4 mg/ℓ NO_3

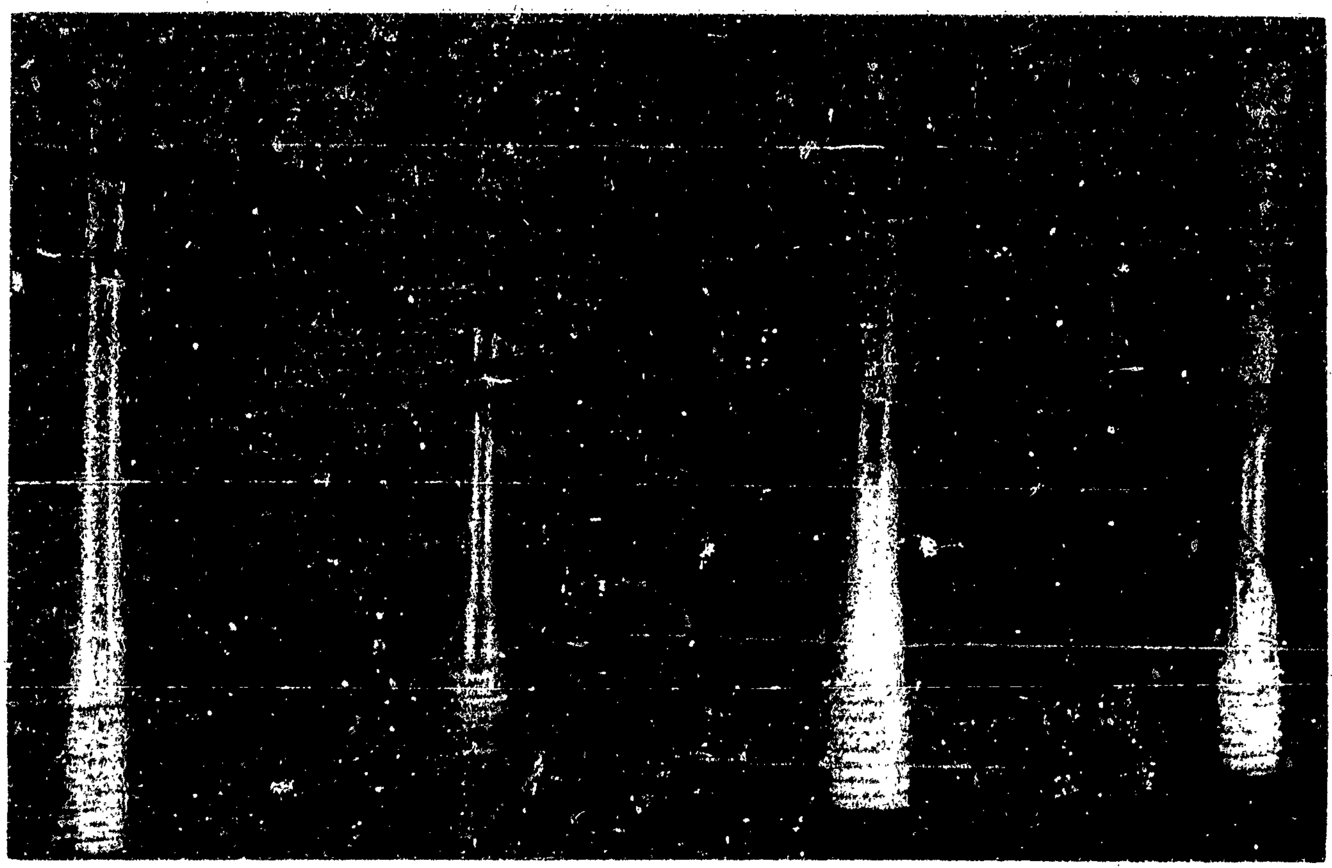
Figure 18 SPECIMENS OF CASTING ALLOY 43S
(ALL EXPOSED FOR 6 MONTHS)



AS-CAST WELDED

UNSTRESSED STRESSED UNSTRESSED STRESSED

90% H_2O_2- NO ADDITIVES

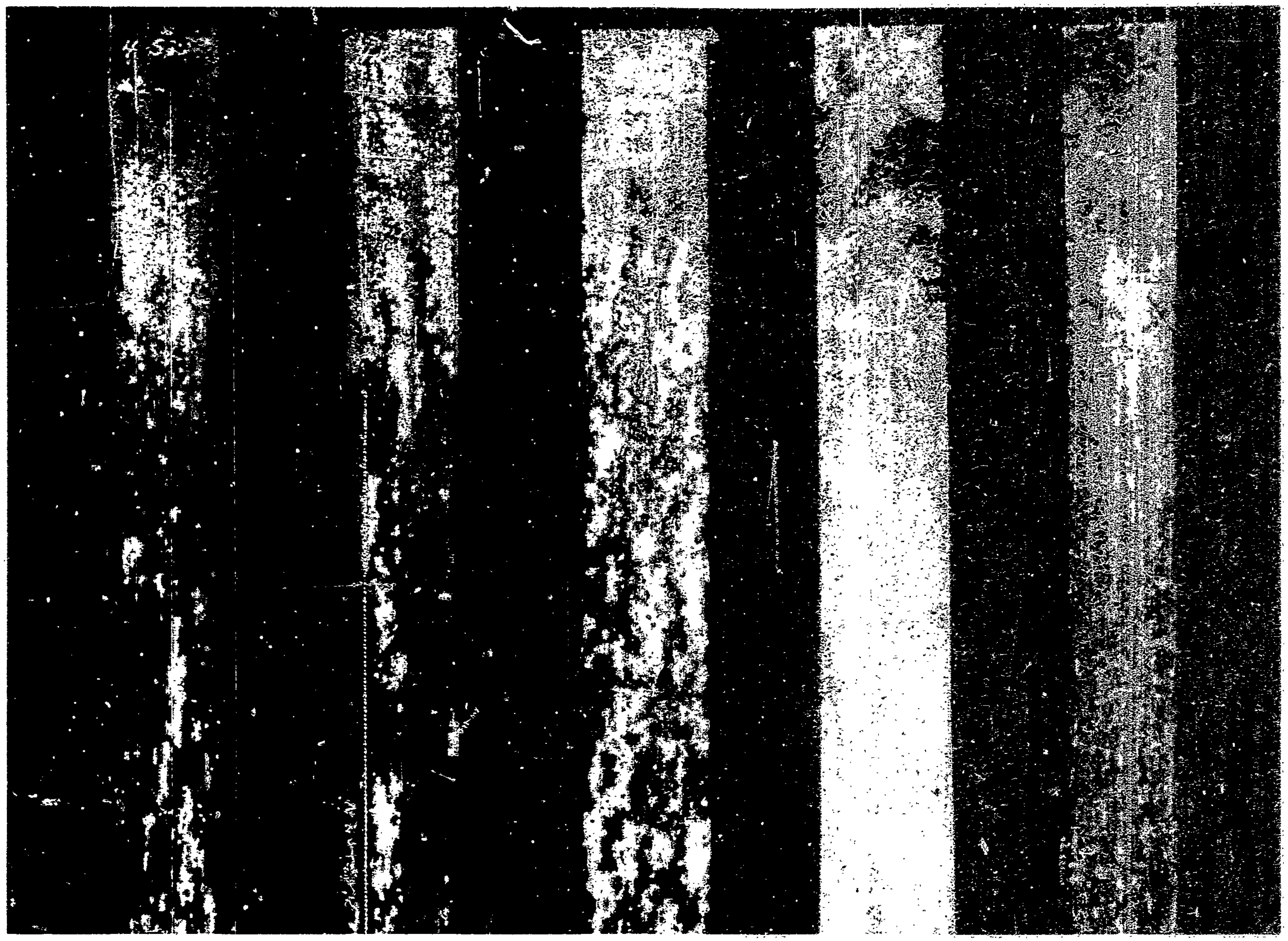


AS-CAST WELDED

UNSTRESSED STRESSED UNSTRESSED STRESSED

90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3

Figure 19 SPECIMENS OF CASTING ALLOY B-214
(ALL EXPOSED FOR 6 MONTHS)



5652 9 DAYS | 5254 9 DAYS | 6363 | 6061 6 MO. | 5086 9 DAYS

90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3
(ALL SPECIMENS STRESSED DURING EXPOSURE)

Figure 20 SPECIMENS WHICH WERE GIVEN A "SENSITIZING" TREATMENT

5652 9 DAYS | 5254 9 DAYS | 6363 9 DAYS | 6061 3 MOS. | 5086 9 DAYS

90% H_2O_2 + 3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3

(ALL SPECIMENS STRESSED DURING EXPOSURE)

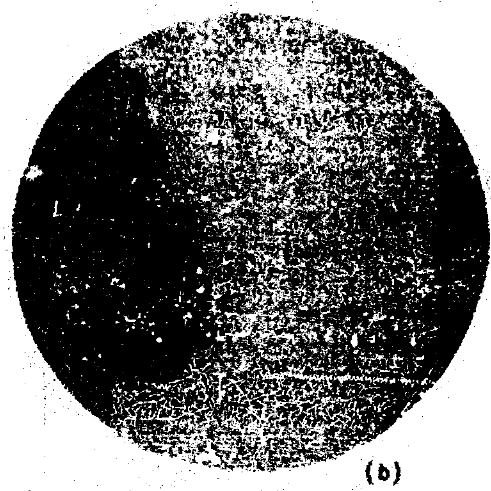
Figure 21 WELDED SPECIMENS WHICH WERE GIVEN A "SENSITIZING" TREATMENT

$90\%\ H_2O_2$ — BASE METAL SIDE 6 MO. — OUTER SIDE 6 MO.

$90\%\ H_2O_2 + 3\,mg/\ell\ C\ell$ AND $4\,mg/\ell\ NO_3$ — BASE METAL SIDE 9 DAYS — OUTER SIDE 9 DAYS

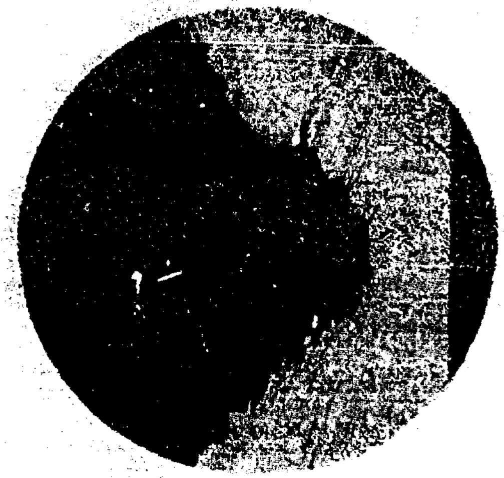
Figure 22 WELDED 1260 CLADDING REMOVED FROM 5086 BACKING

(a) ALLOY 1260
LIQUID-VAPOR INTERFACE
61 DAYS
H_2O_2+ADDITIVES



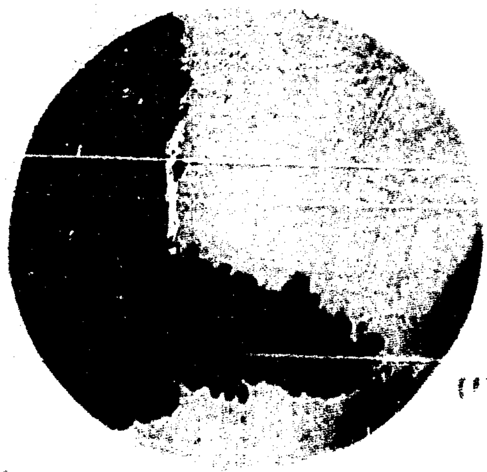
(b) ALLOY 1100
LIQUID-VAPOR INTERFACE
61 DAYS
H_2O_2+ ADDITIVES

(c) ALLOY 5652
LIQUID-VAPOR INTERFACE
6 MONTHS
H_2O_2+ ADDITIVES



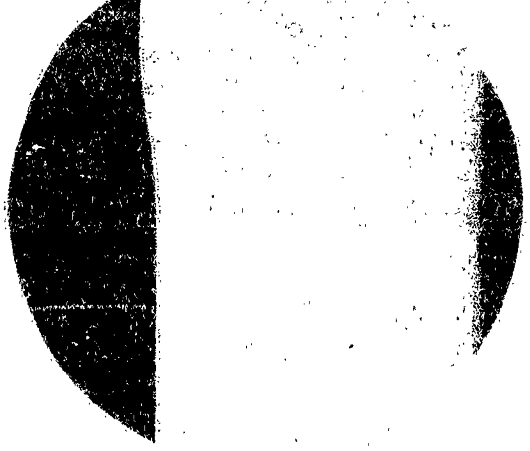
(d) ALLOY 5086
LIQUID-VAPOR INTERFACE
6 MONTHS
H_2O_2+ ADDITIVES

(e) ALLOY 5652
VAPOR PHASE
6 MONTHS
NO ADDITIVES



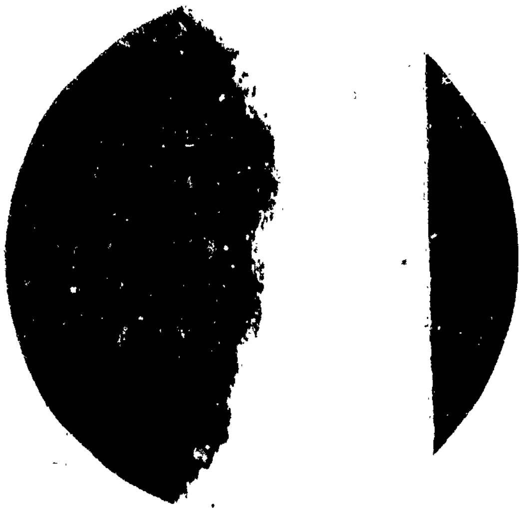
(f) ALLOY 52[illegible]
VAPOR PHASE
6 MONTHS
NO ADDITIVES

Figure 2[illegible] METALLOGRAPHIC SECTIONS SHOWING TYPE OF ATTACK IN THE VAPOR PHASE AND AT LIQUID-VAPOR INTERFACE. 25X - KELLERS ETCH



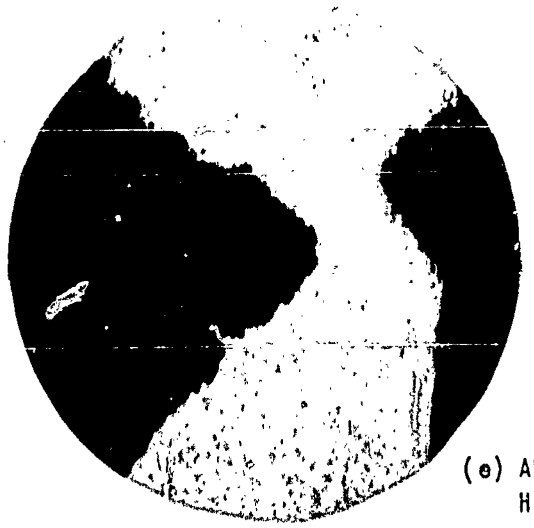
(a) ALLOY 1060
GENERAL ATTACK
36 DAYS
H_2O_2 + ADDITIVES

(b) ALLOY 6363
LOCALIZED ATTACK
36 DAYS
H_2O_2 + ADDITIVES

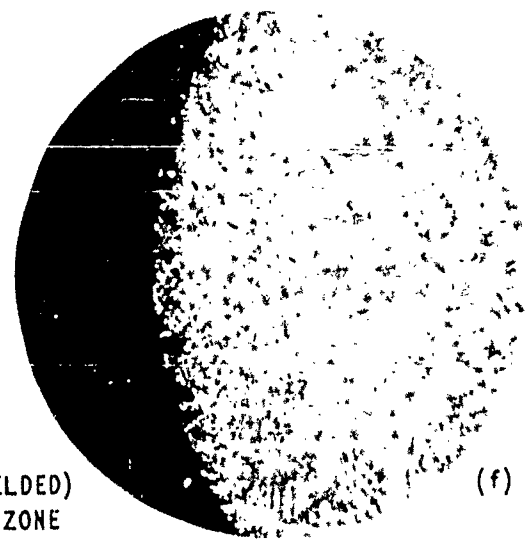


(c) ALLOY 6061
LOCALIZED ATTACK
6 MONTHS
H_2O_2 + ADDITIVES

(d) ALLOY 3003 (WELDED)
HEAT AFFECTED ZONE
6 MONTHS
H_2O_2 + ADDITIVES

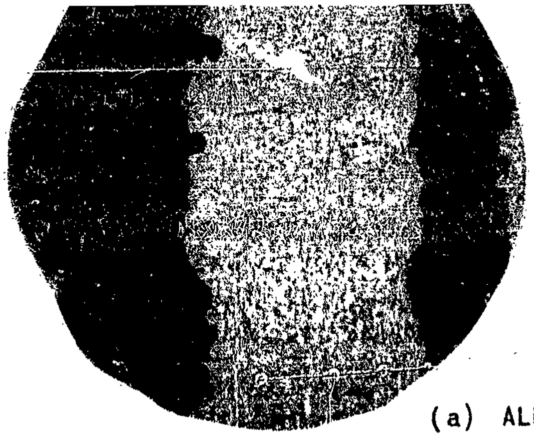


(e) ALLOY 6061 (WELDED)
HEAT AFFECTED ZONE
6 MONTHS
H_2O_2 + ADDITIVES



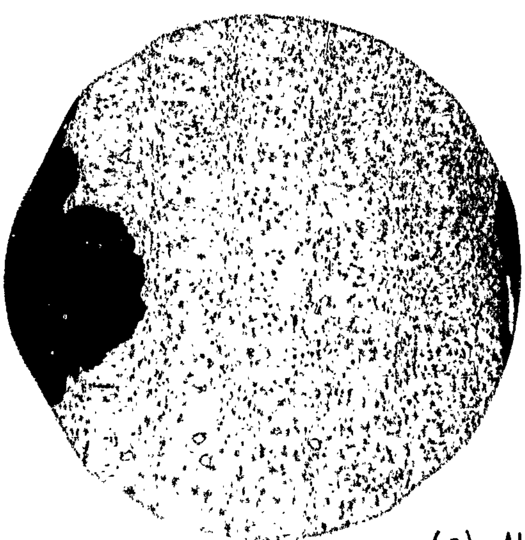
(f) CAST ALLOY 356
GENERAL ATTACK
34 DAYS
H_2O_2 + ADDITIVES

Figure 24 METALLOGRAPHIC SECTIONS TAKEN FROM VARIOUS SPECIMENS SHOWING GENERAL AND LOCALIZED ATTACK IN LIQUID PEROXIDE. 25X - KELLERS ETCH



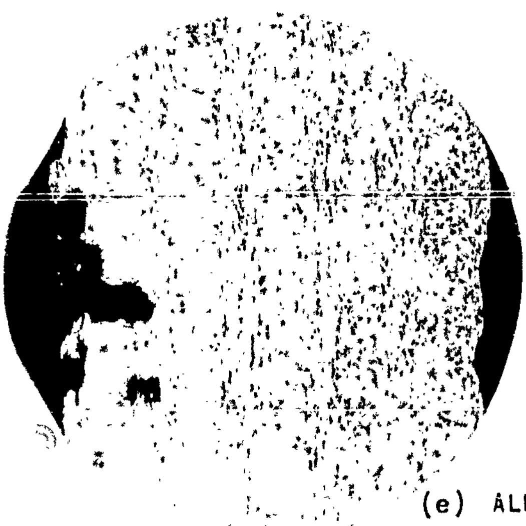
(a) ALLOY 5652 (SENSITIZED)
GENERAL ATTACK
9 DAYS
H_2O_2+ ADDITIVES

(b) ALLOY 5254 (SENSITIZE
GENERAL ATTACK
9 DAYS
H_2O_2+ ADDITIVES

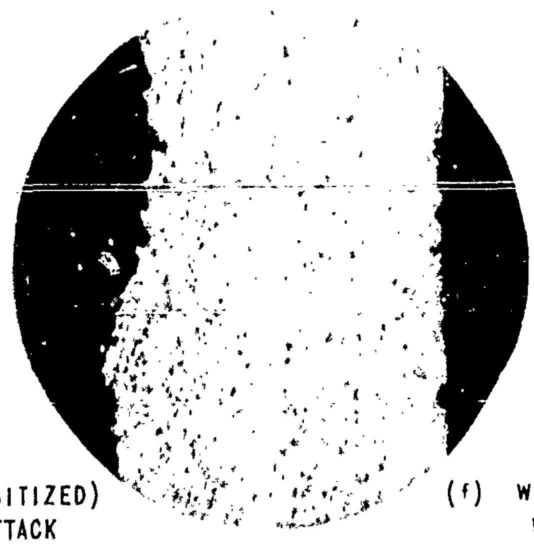


(c) ALLOY 6363 (SENSITIZED)
GENERAL ATTACK
9 DAYS
H_2O_2+ ADDITIVES

(d) ALLOY 5086 (SENSITIZED
GENERAL ATTACK
9 DAYS
H_2O_2+ADDITIVES

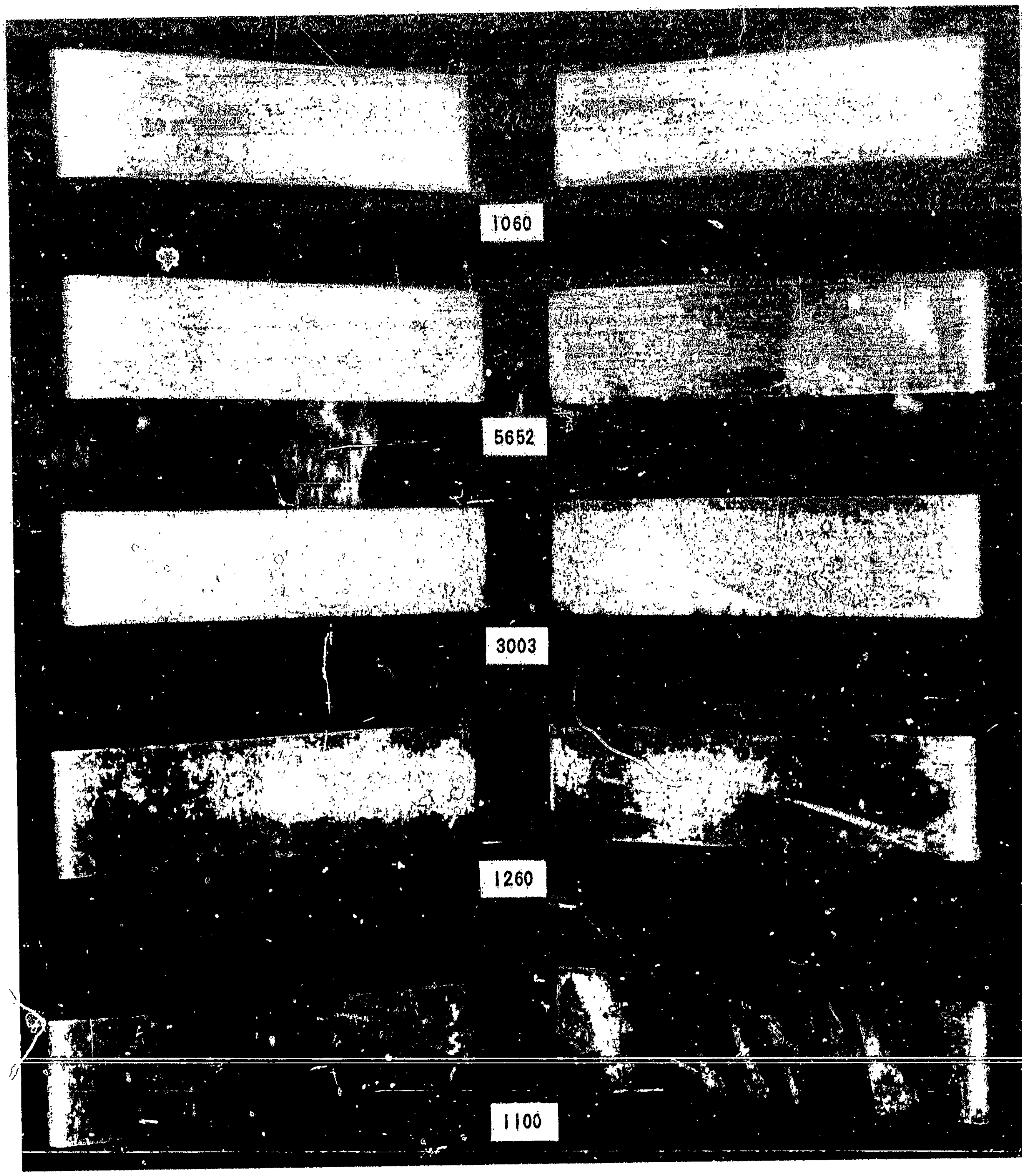


(e) ALLOY 6061 (SENSITIZED)
VAPOR PHASE ATTACK
6 MONTHS
H_2O_2+ ADDITIVES



(f) WELDED 6061 (SENSITI
WELD ZONE - 3 MONTH
H_2O_2+ ADDITIVES

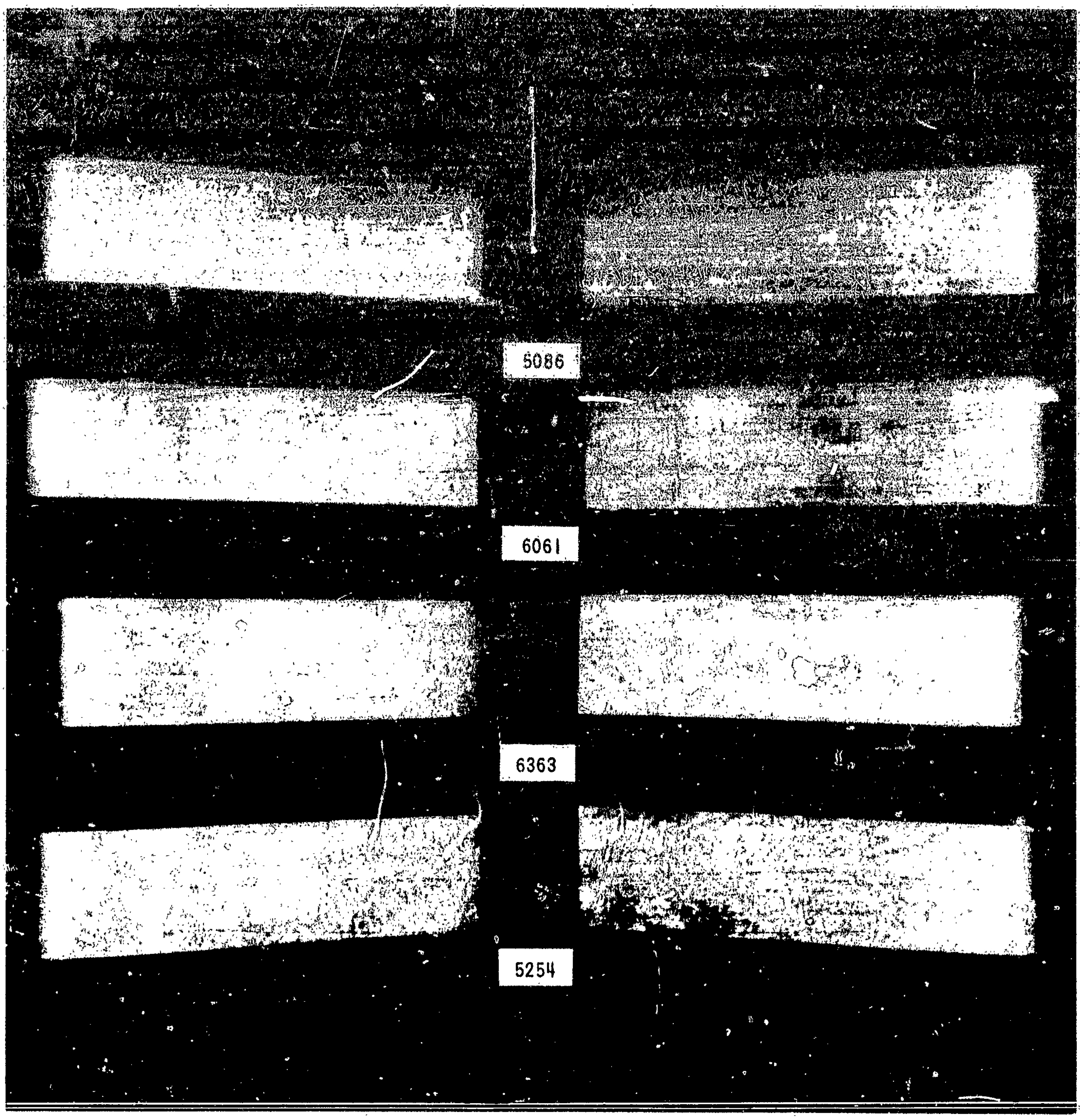
Figure 25 METALLOGRAPHIC SPECIMENS FROM SENSITIZED ALLOYS. 25X - KELLERS ETCH



90% H_2O_2
NO ADDITIVES

90% H_2O_2 +
3 mg/Cl AND 4 mg/l NO_3

Figure 26 PREFORMED STRESS CORROSION SPECIMENS OF ALLOYS 1100, 1260, 3003, 5652 AND 1060 AFTER 6 MONTH EXPOSURE



90% H_2O_2
NO ADDITIVES

90% H_2O_2+
3 mg/ℓ Cℓ AND 4 mg/ℓ NO_3

Figure 27 PREFORMED STRESS CORROSION SPECIMENS OF ALLOYS 5254, 6363, 6061 AND 5086 AFTER 6 MONTH EXPOSURE

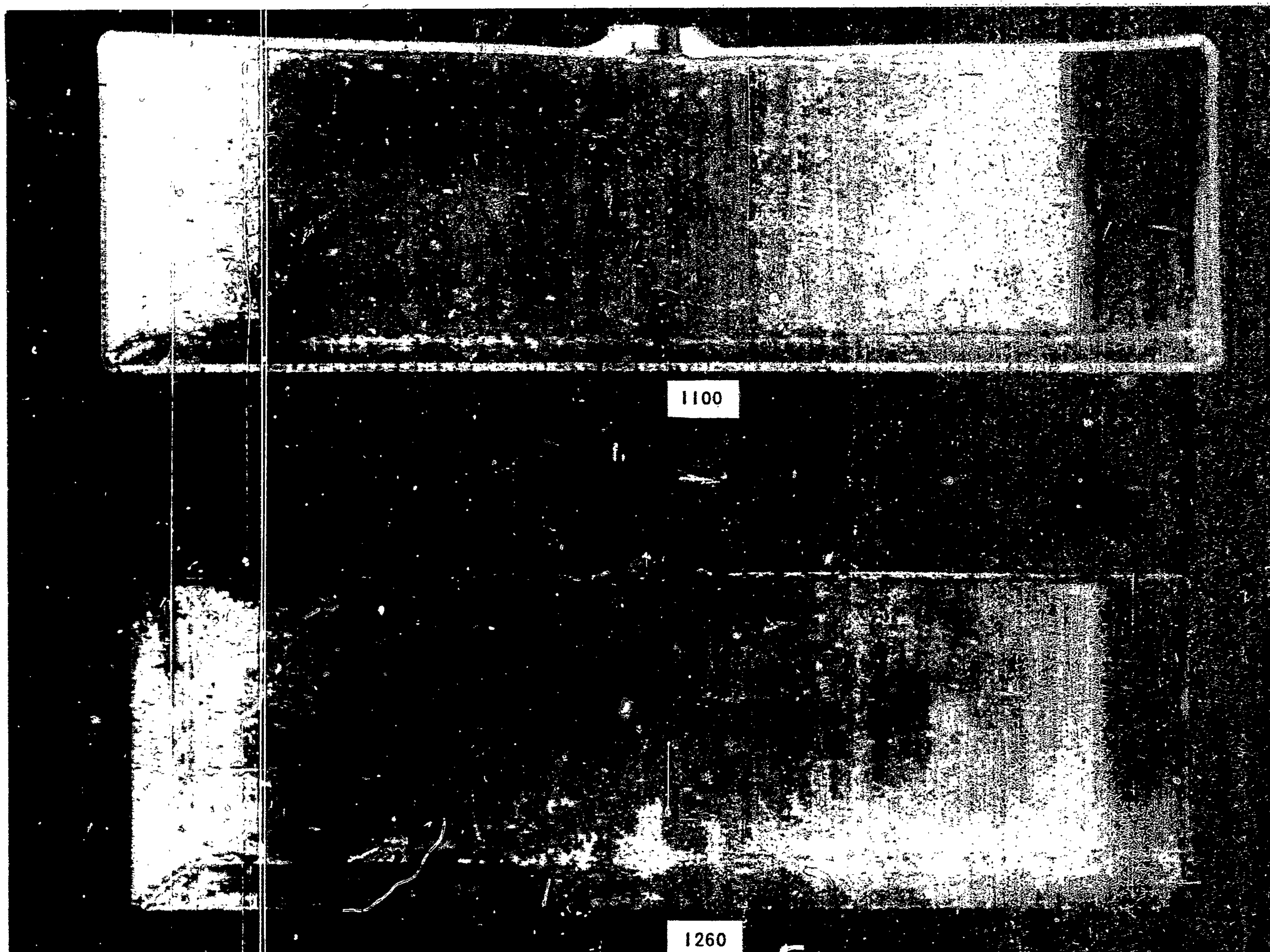


Figure 28 TANK SPECIMENS OF 1100 AND 1260 ALLOYS AFTER 6 MONTH SLOSHING TEST HALF-FILLED WITH 90% H_2O_2- NO ADDITIVES

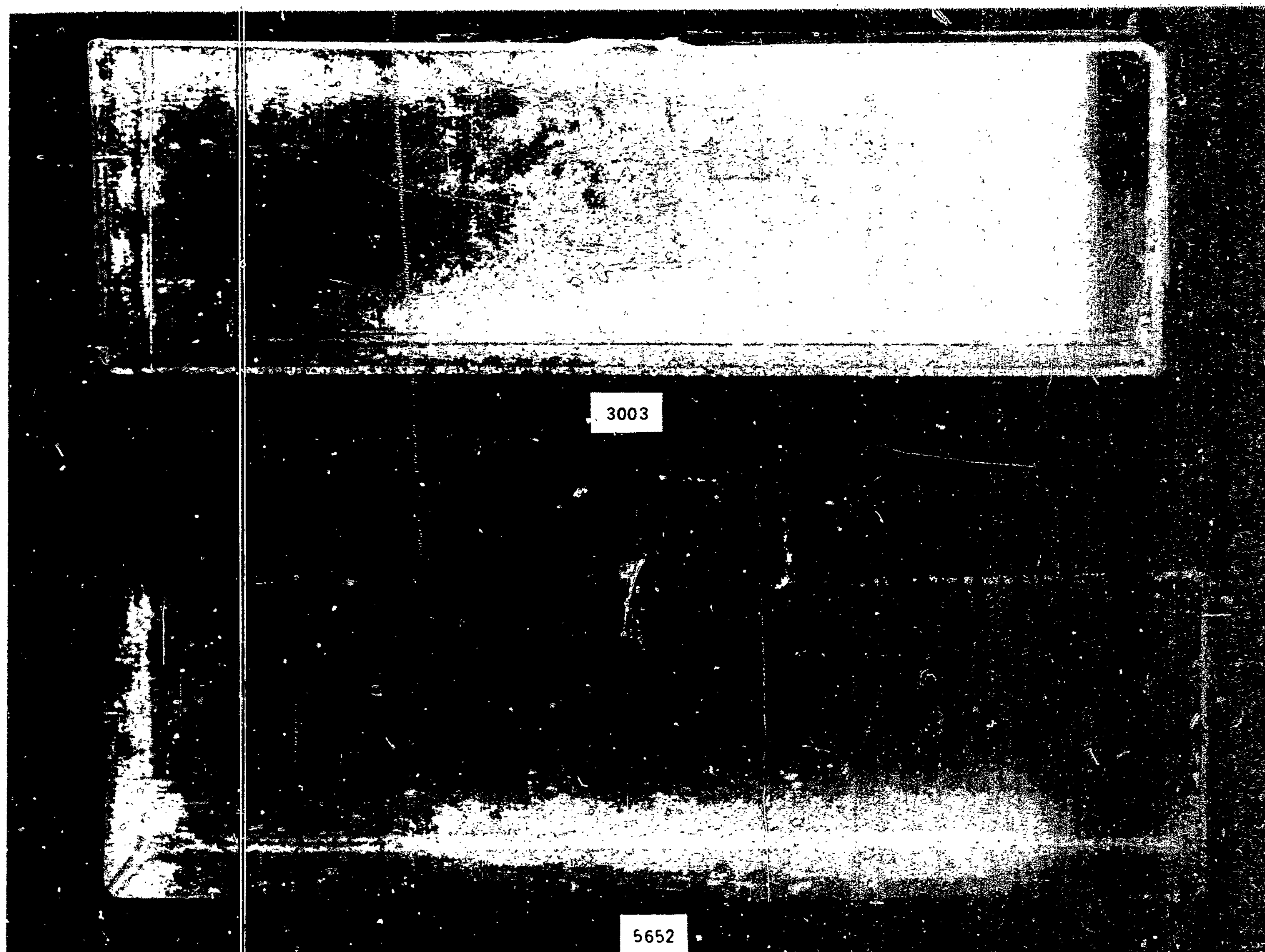


Figure 29 TANK SPECIMENS OF 3003 AND 5652 ALLOYS AFTER 6 MONTH SLOSHING TEST HALF-FILLED WITH 90% H_2O_2,- NO ADDITIVES

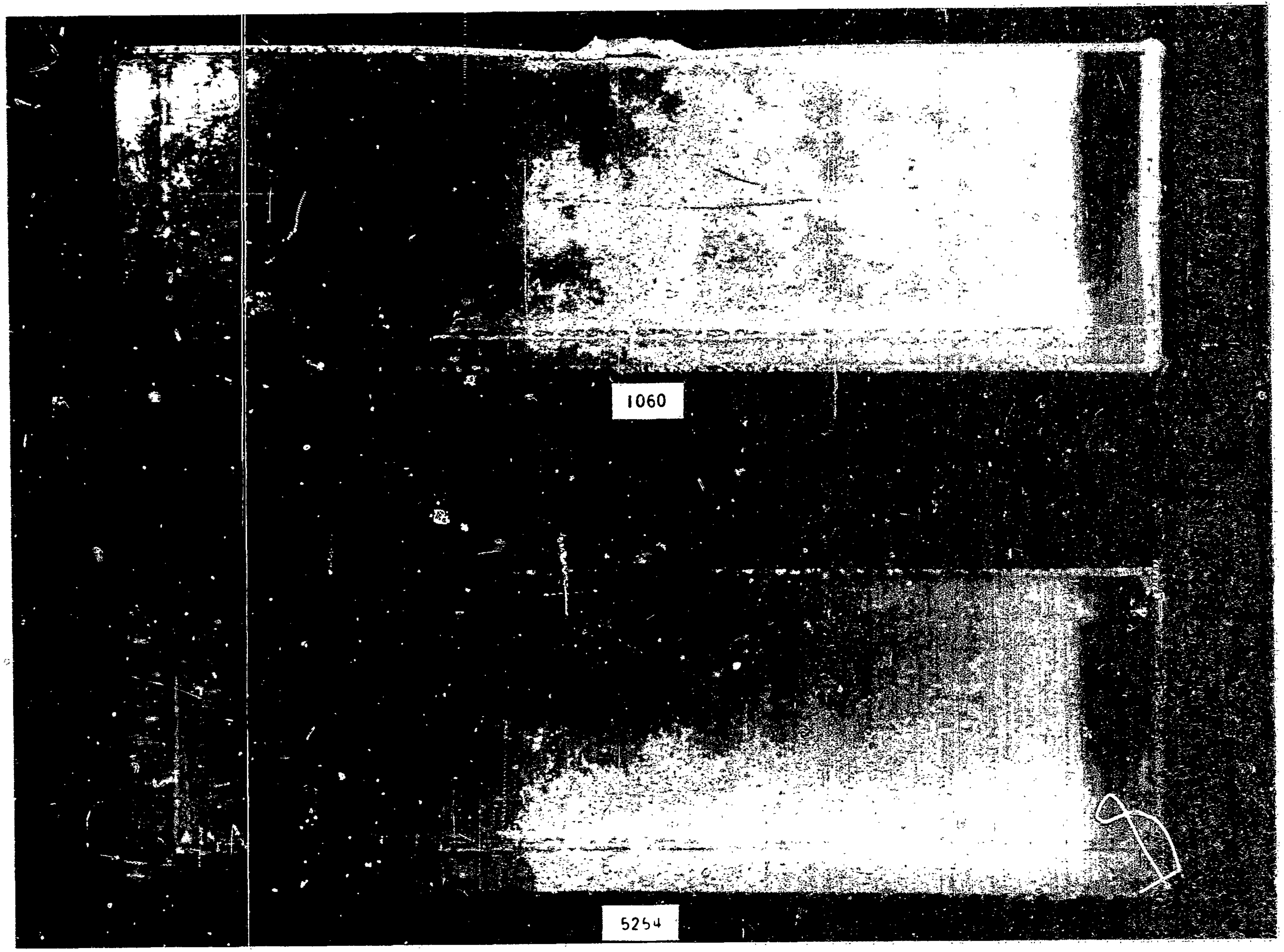


Figure 30 TANK SPECIMENS OF 1060 AND 5254 ALLOYS AFTER 6 MONTH SLOSHING TEST HALF-FILLED WITH 90% H_2O_2- NO ADDITIVES

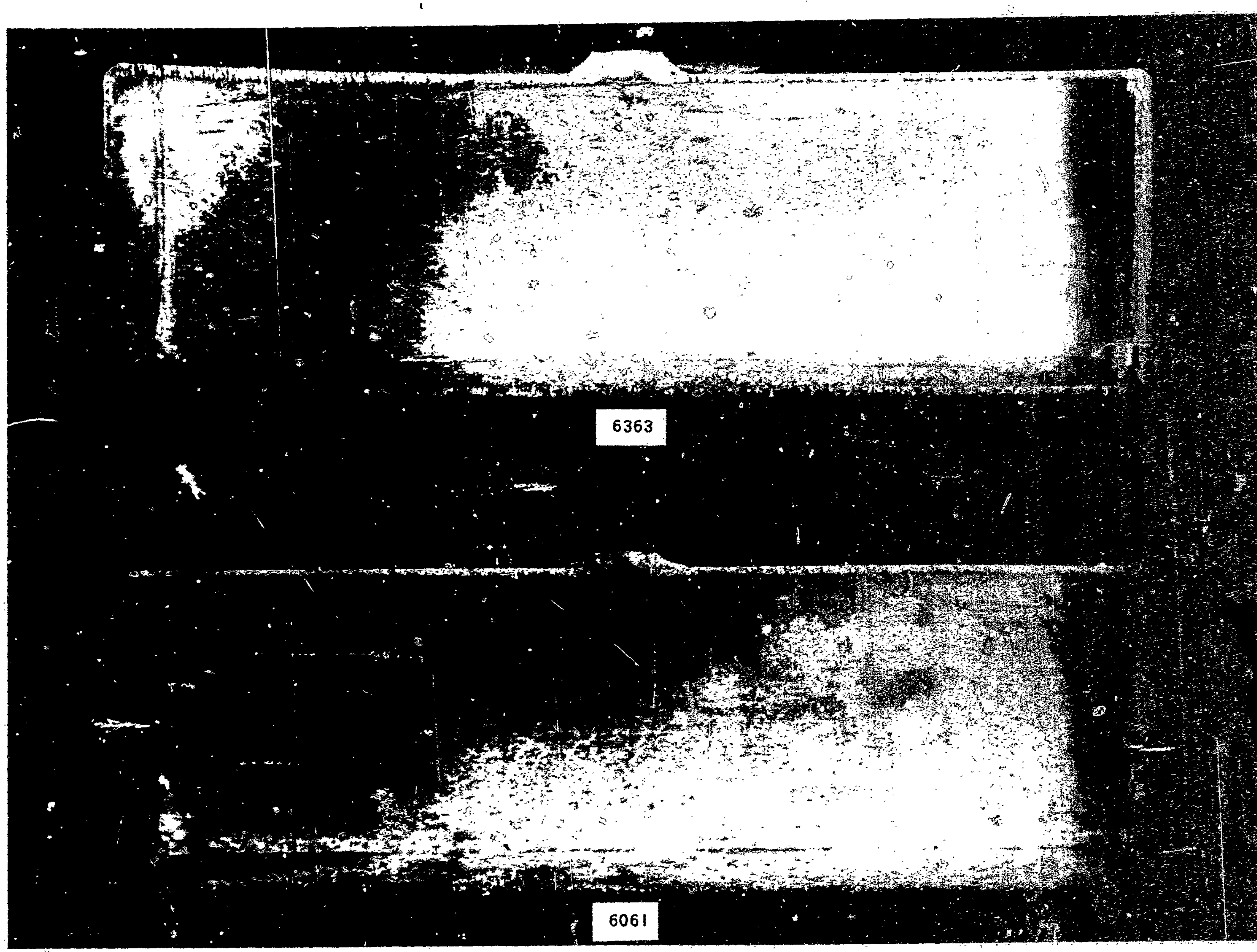


Figure 31 TANK SPECIMENS OF 6363 AND 6061 ALLOYS AFTER 6 MONTH SLOSHING TEST HALF-FILLED WITH 90% H_2O_2 - NO ADDITIVES.

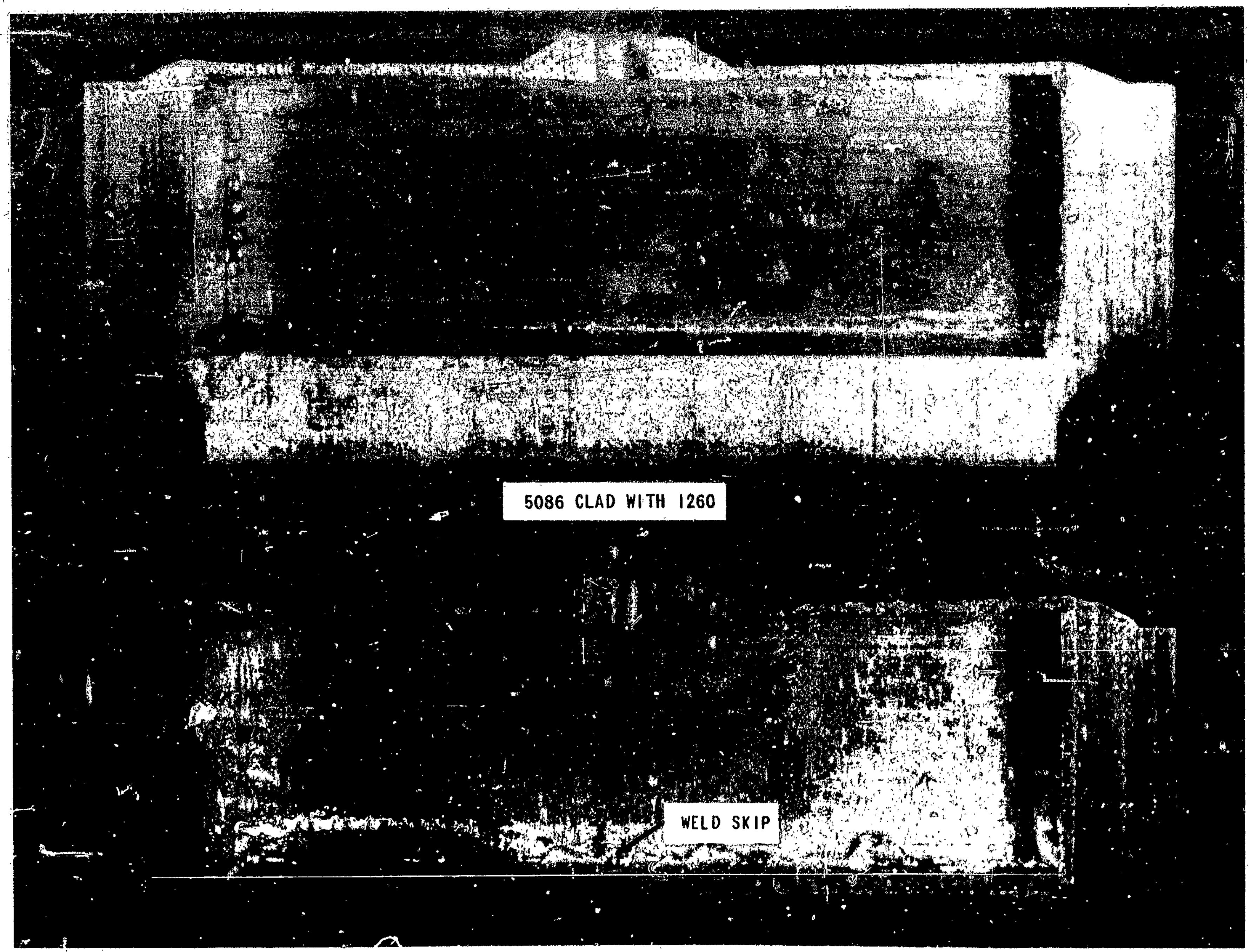


Figure 32 TANK SPECIMENS OF 5086 ALLOY CLAD WITH 1260 AFTER 6 MONTH SLOSHING TEST HALF-FILLED WITH 90% H_2O_2- NO ADDITIVES. DISCONTINUITY IN 1260 SEAL BEAD WAS PURPOSELY LEFT IN LOWER TANK.

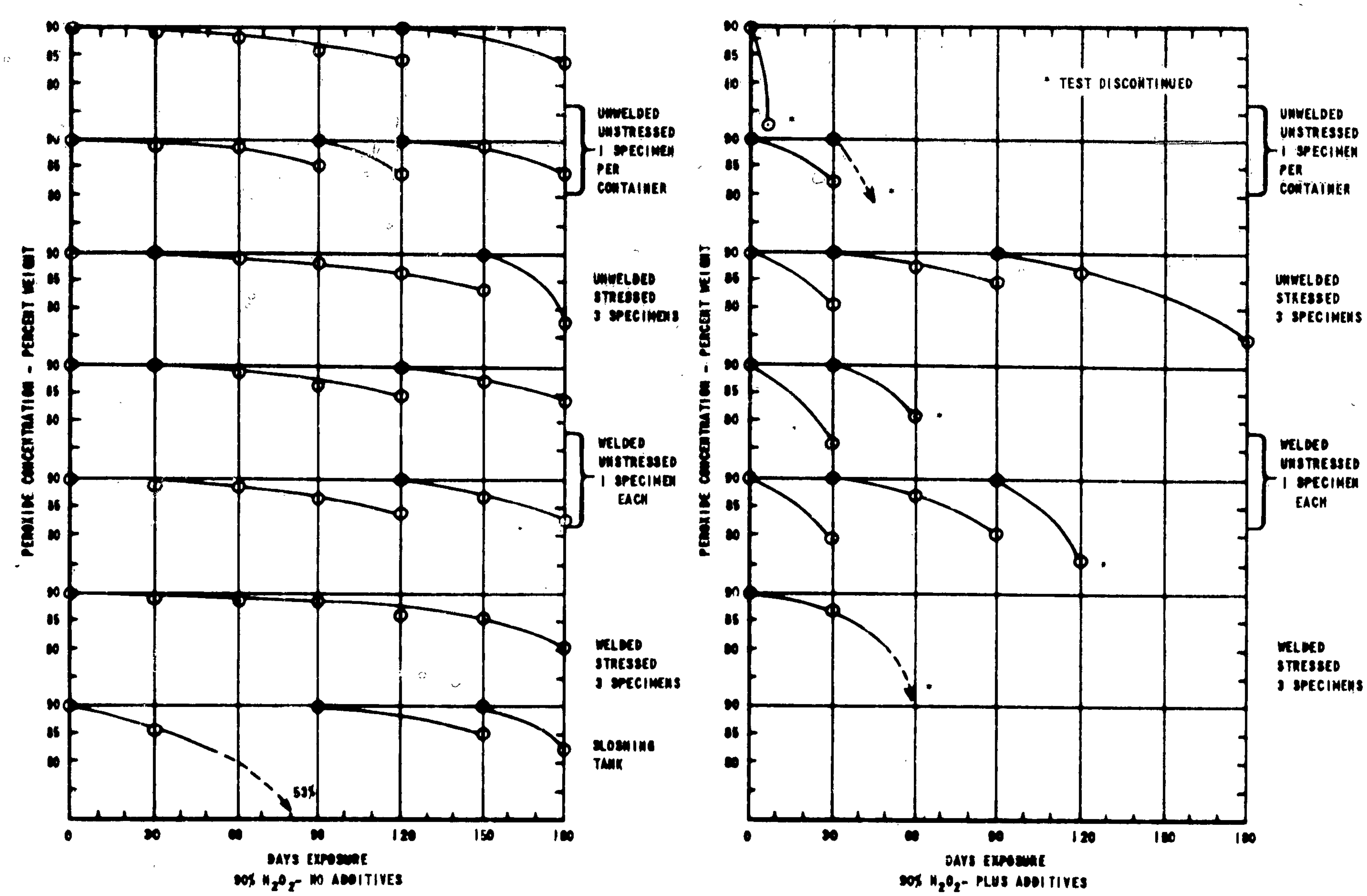


Figure 33 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 1100

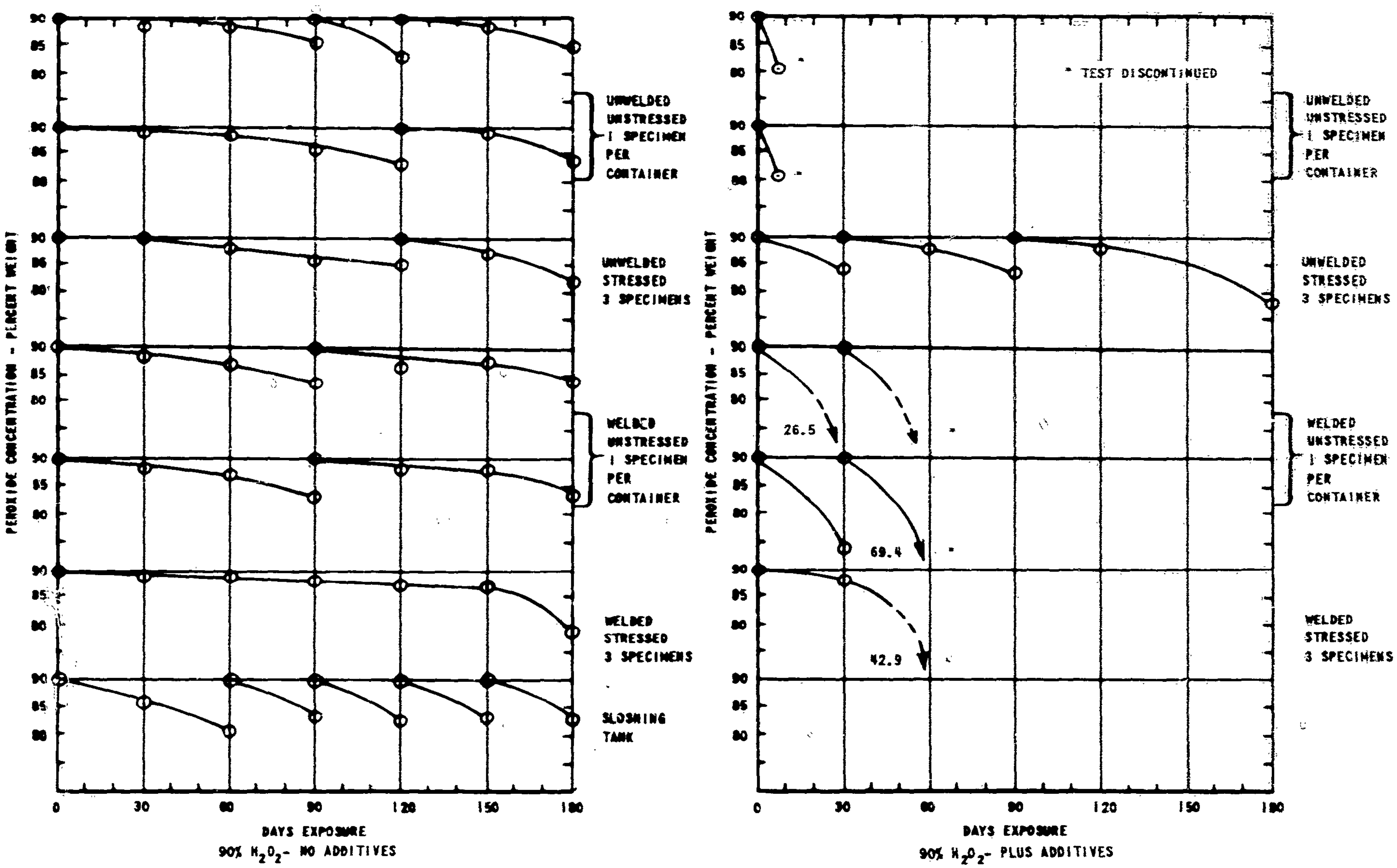


Figure 34 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 1260

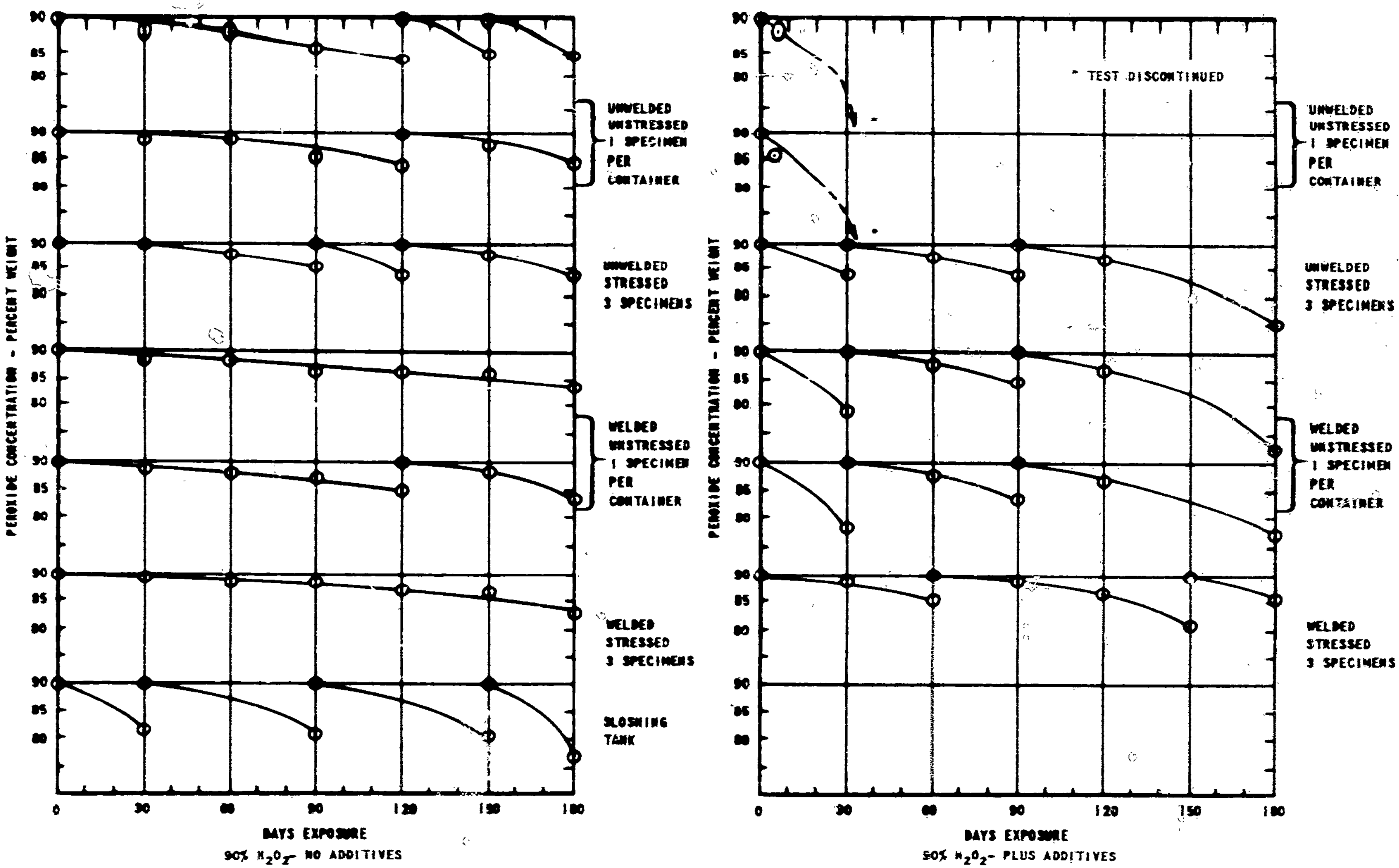


Figure 35 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 3003

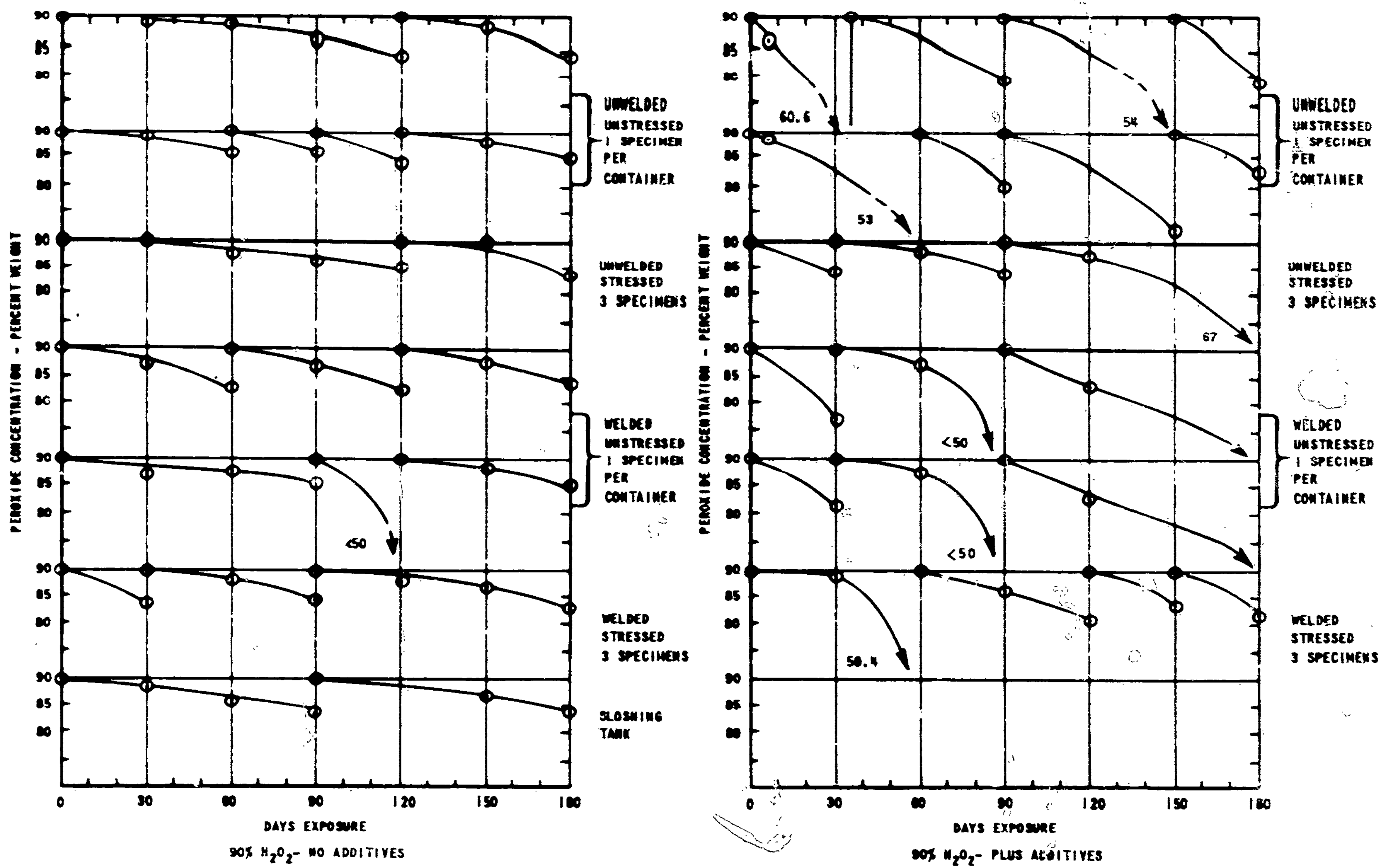


Figure 36 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 5652

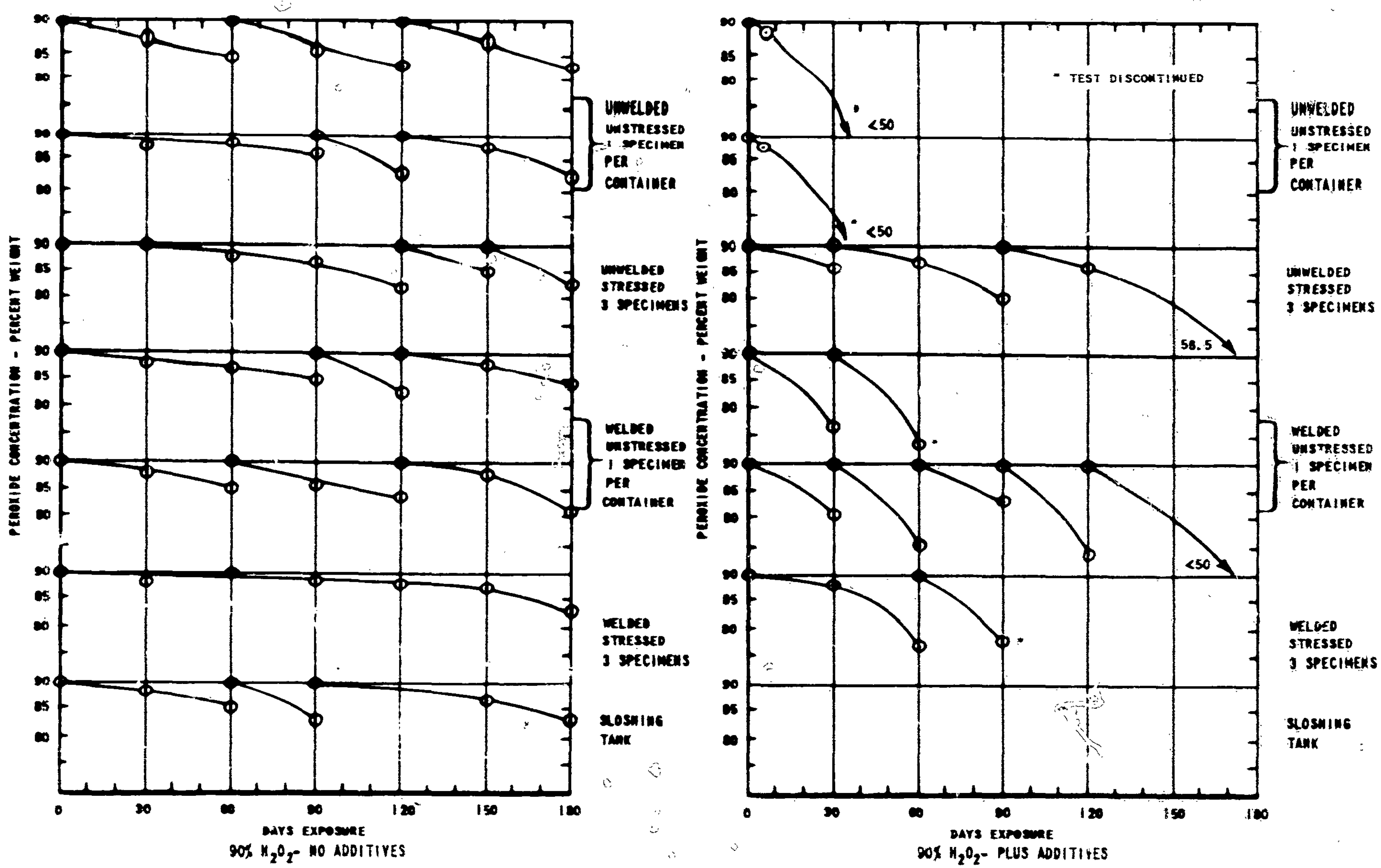


Figure 37 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 1060

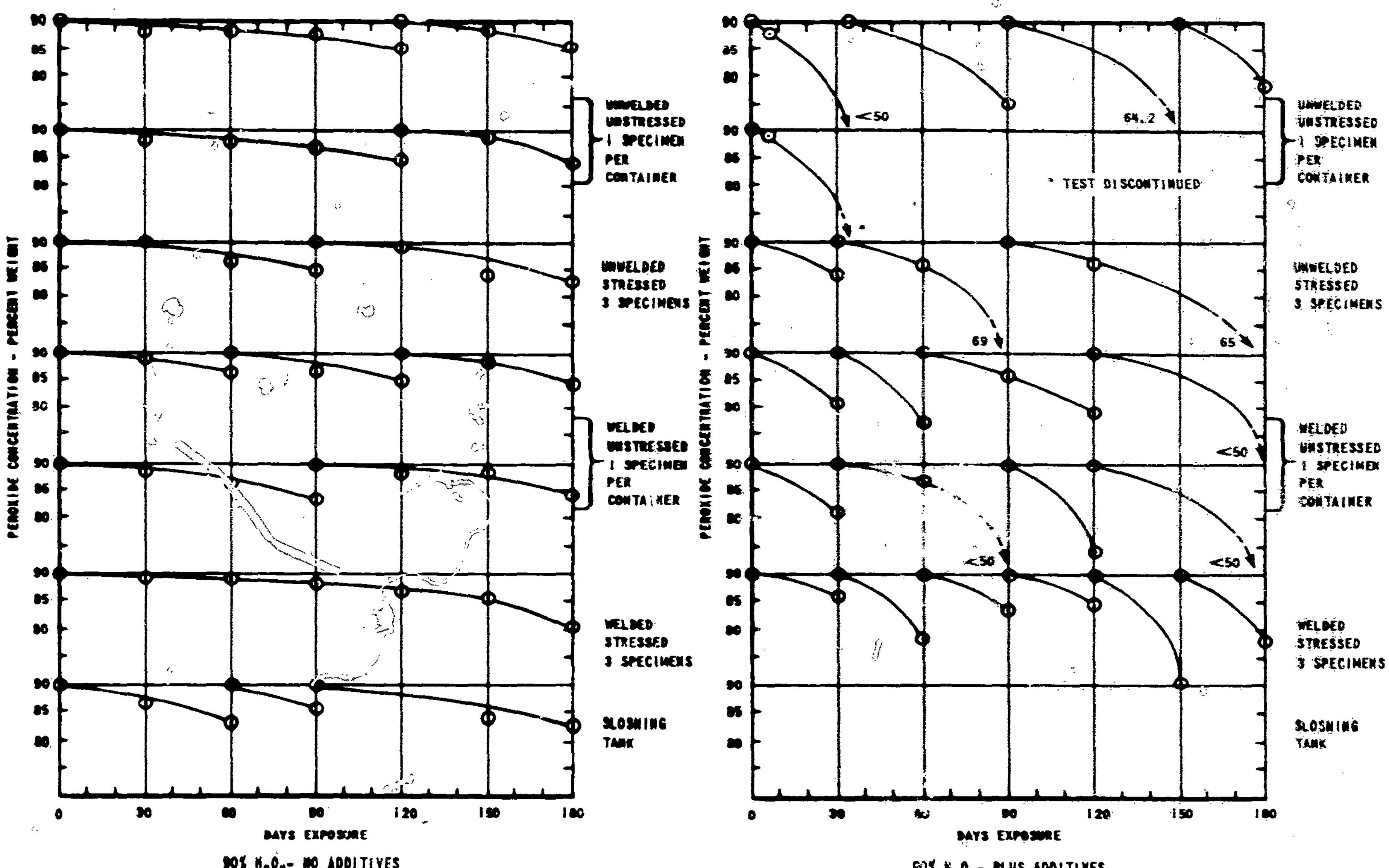


Figure 38 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 5254

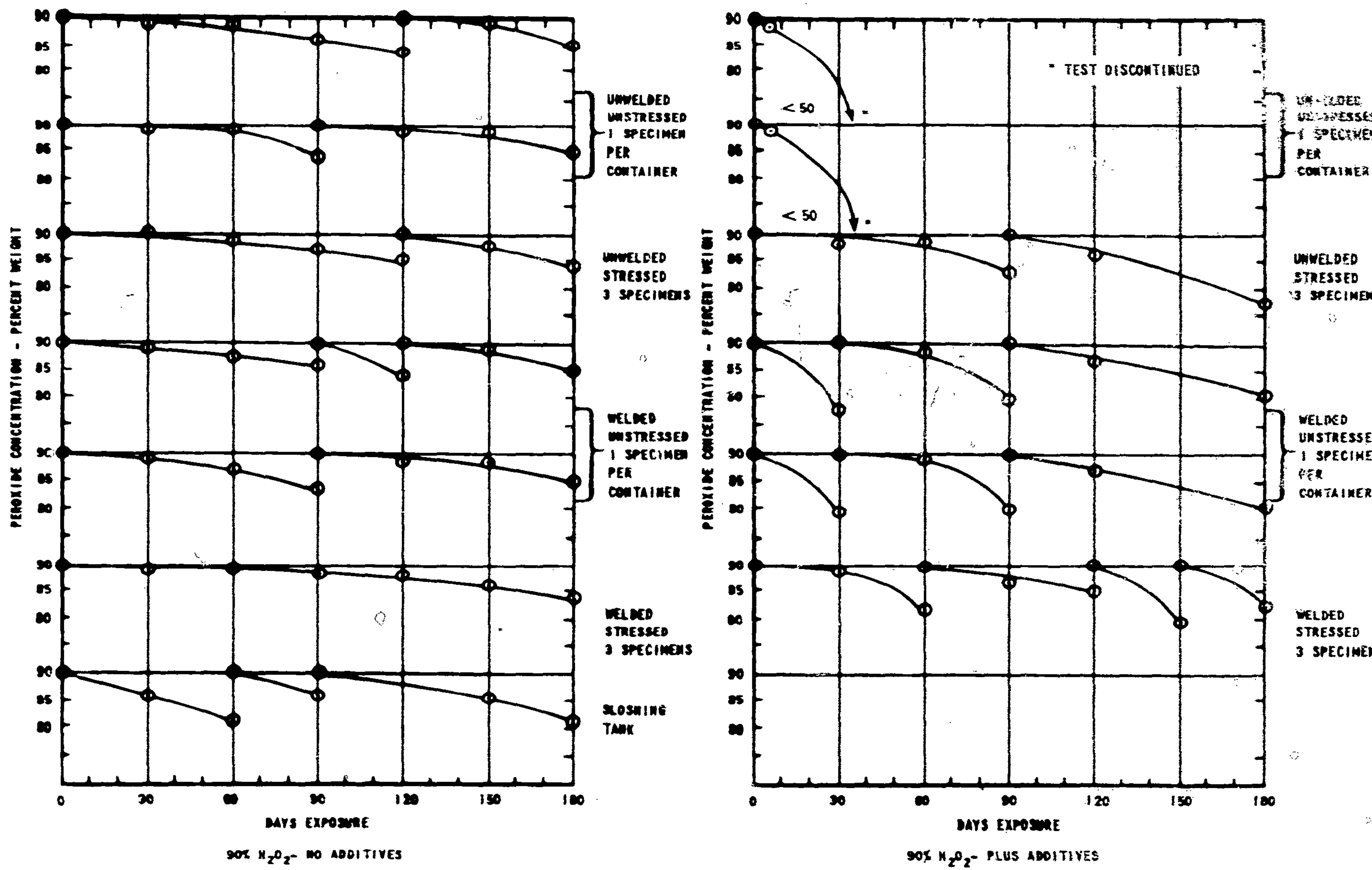


Figure 39 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 6363

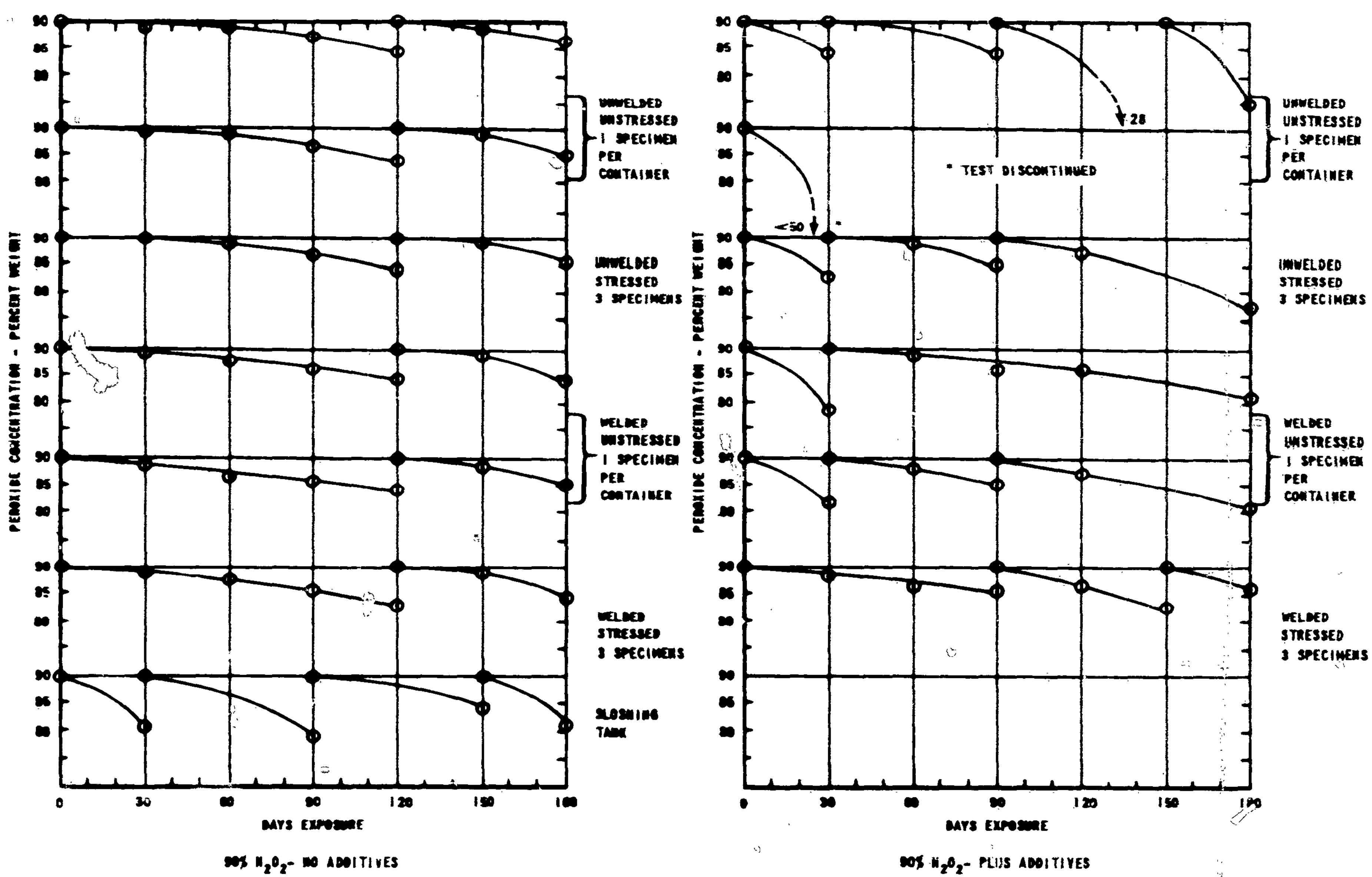


Figure 40 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 6061

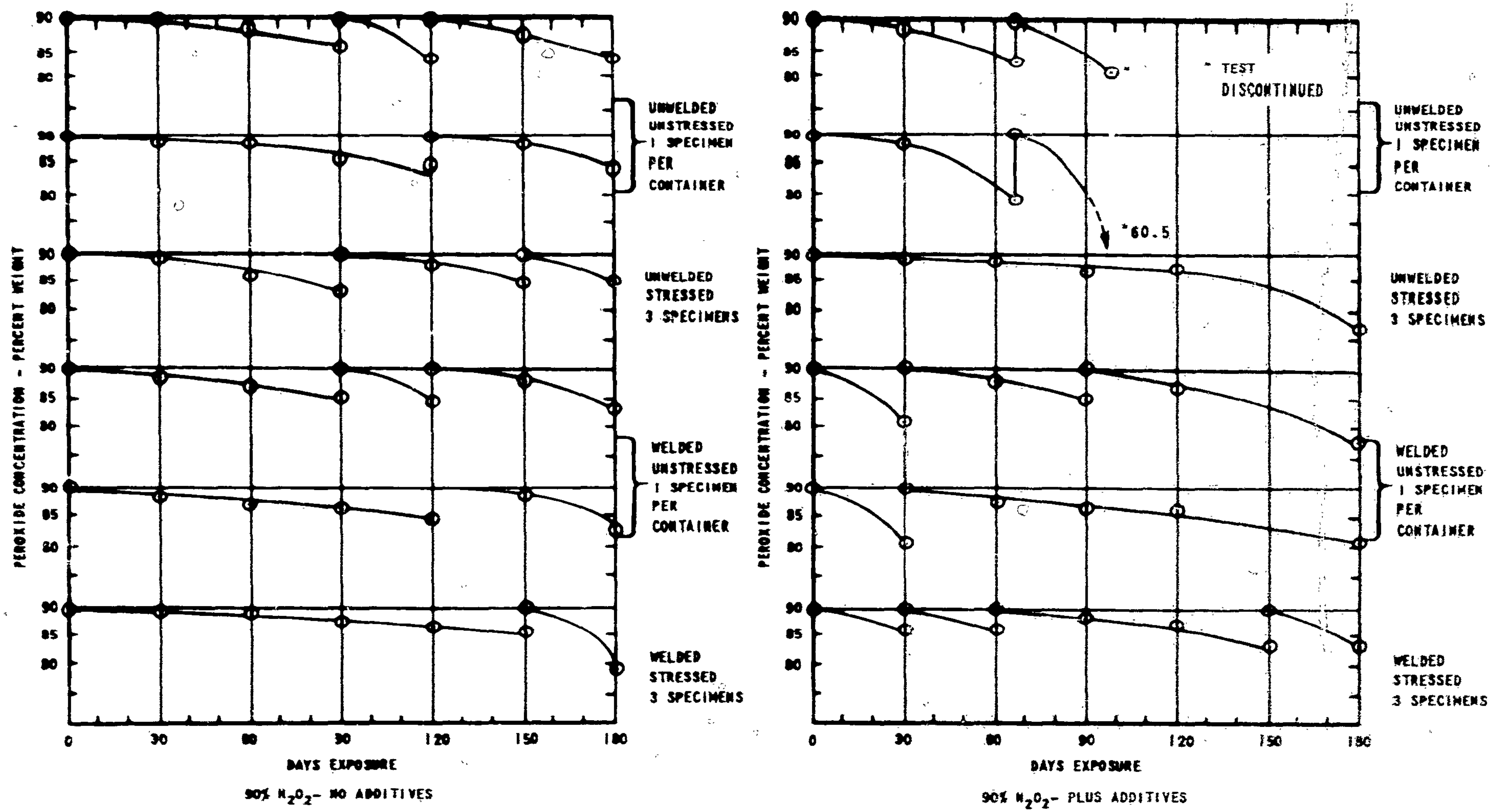


Figure 41 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOY 5086

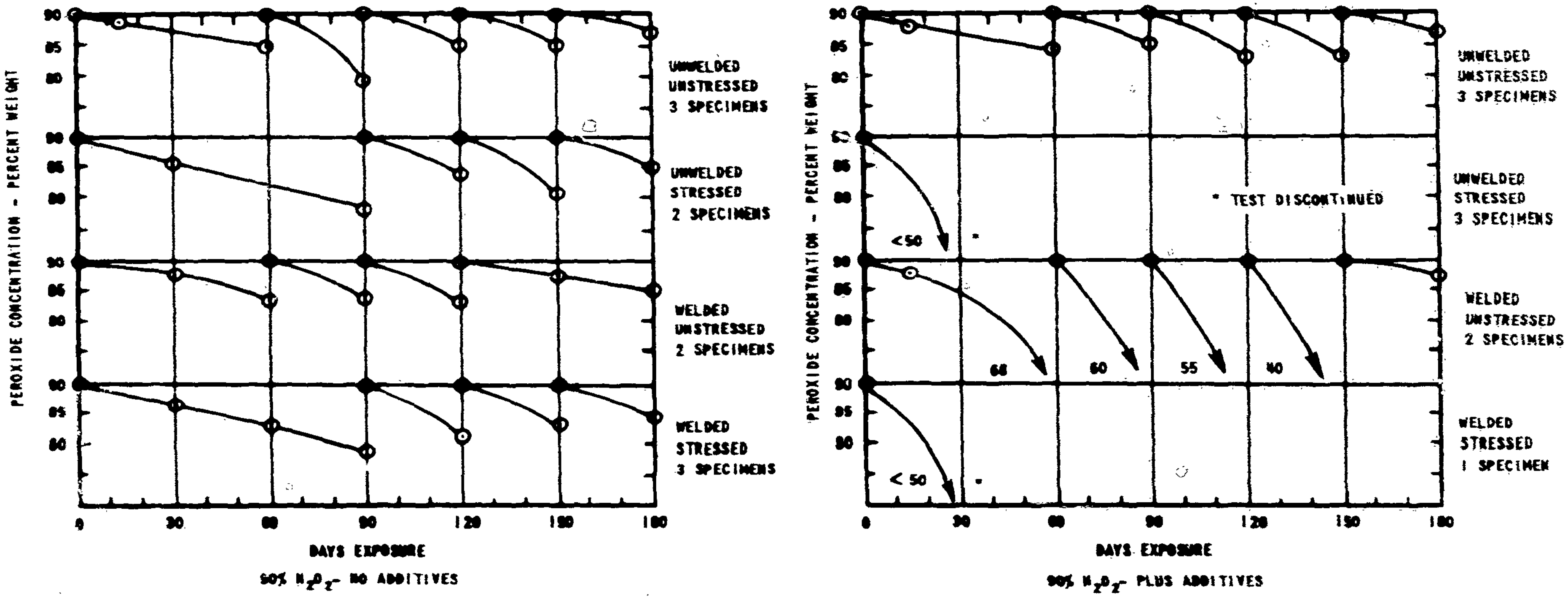
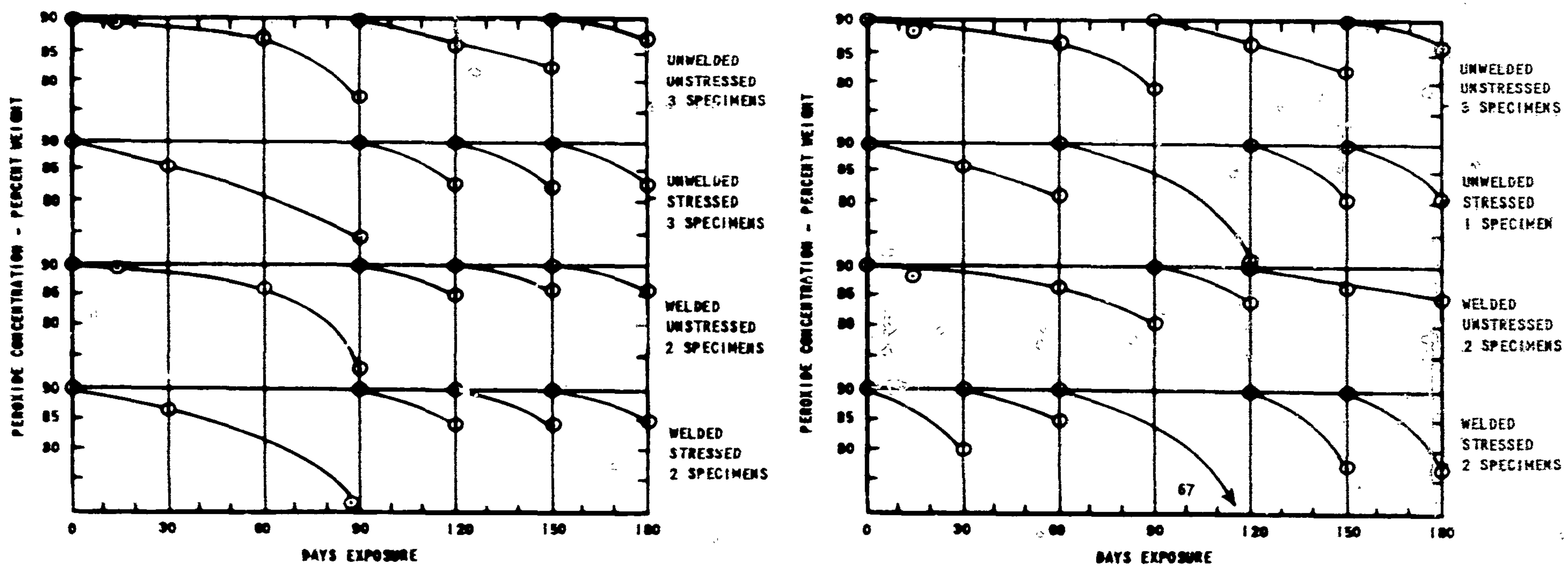


Figure 42 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR CAST ALLOY 356



90% H_2O_2- NO ADDITIVES

Figure 43 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR CAST ALLOY 43S

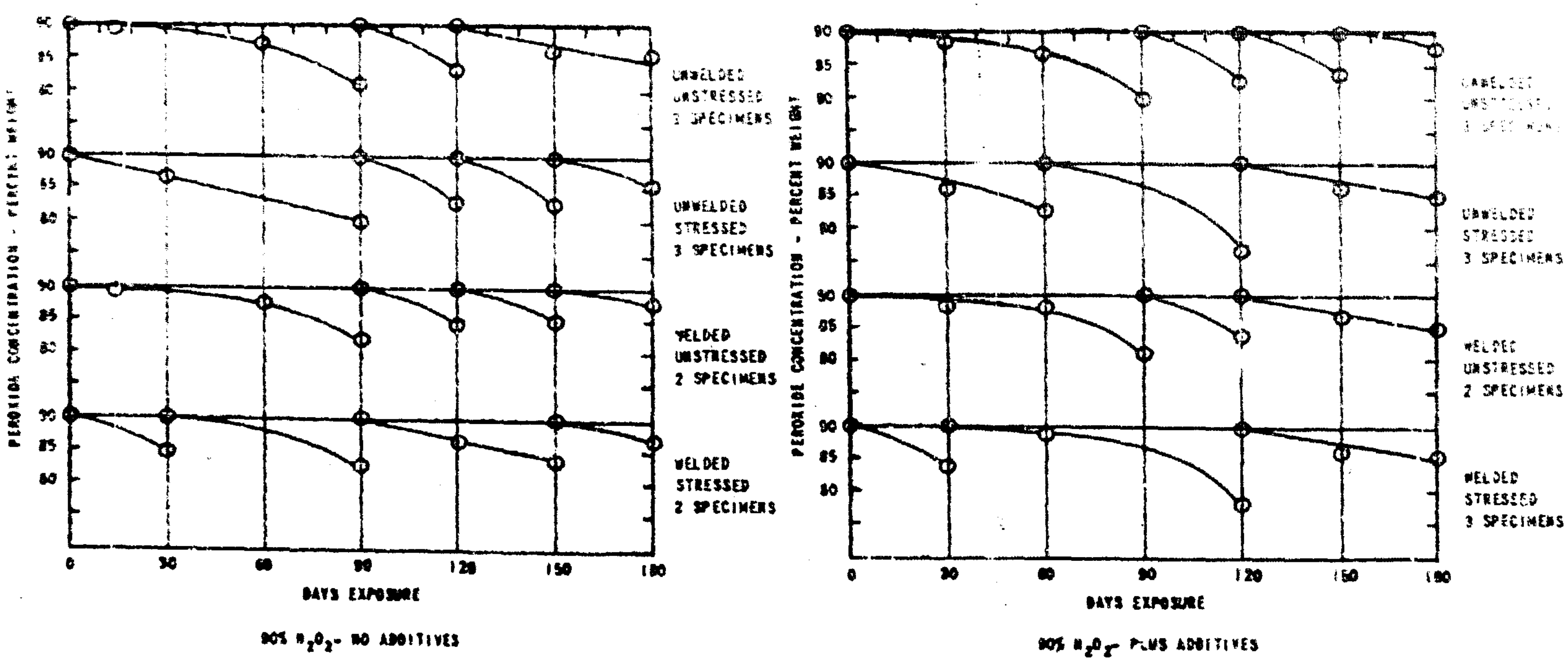


Figure 44 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR CAST ALLOY B21N

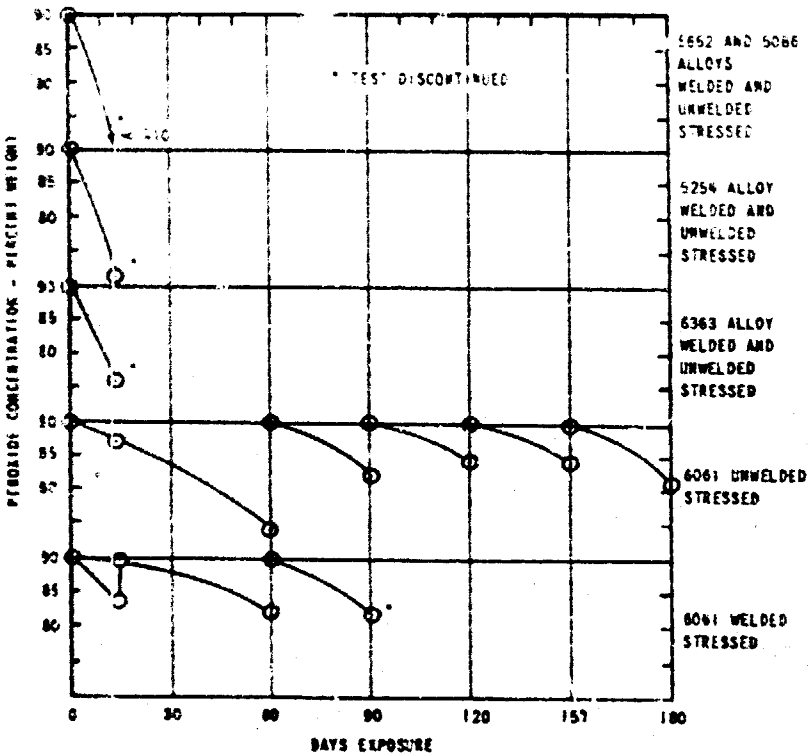


Figure 45 CHANGE IN PEROXIDE CONCENTRATION WITH TIME FOR ALLOYS GIVEN SENSITIZING HEAT TREATMENT

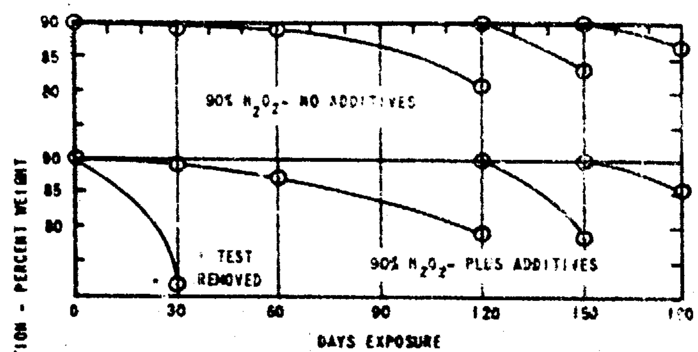


Figure 46 CHANGE IN H_2O_2 CONCENTRATION FOR 1260 CLADDING REMOVED FROM 5086 BASE METAL WELDED WITH 1260 SEAL BEAD (SEE FIG 1)

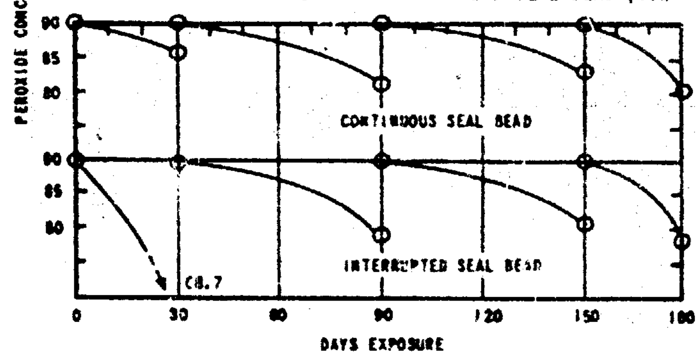


Figure 47 CHANGE IN H_2O_2 CONCENTRATION IN 1260 CLAD 5086 SLOSHING TANKS WELDED WITH 1260 SEAL BEAD AND 5356 FILLER PASSES (SEE FIG. 32)